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Lessons learned from urban river restoration projects: application of restoration treatments on the Los Angeles River.

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This Master's Project

LESSONS LEARNED FROM URBAN RIVER RESTORATION PROJECTS: APPLICATION OF
RESTORATION TREATMENTS ON THE LOS ANGELES RIVER

by

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List of Acronyms

CWA	Clean Water Act
DDT	Dichlorodiphenyltrichloroethane
DWG	Dominguez Wetland Gap
FoLAR	Friends of the Los Angeles River
FWUA	Friant Water Users Authority
HGRP	Headworks Groundwater Recharge Project
HSPF	Hydrologic Simulation Program Fortran
LACDPW	Los Angeles County Department of Public Works
LAR	Los Angeles River
LAR-WMP	Los Angeles River Watershed Monitoring Program
LID	Low Impact Design
NRDC	National Resource Defense Council
PCB	Polychlorinated biphenyl
POTW	Publicly-Owned Treatment Works
TMDL	Total Maximum Daily Loads
TWG	Tujunga Wash Greenway
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds

Key Terms

Aquifer – a geologic formation that holds and yields usable amounts of water (Ward and Trimble 2003)

Baseflow- sustained low flow of a stream often due to groundwater inflow to the stream channel (Ward and Trimble 2003)

Ecosystem Services- goods and services that provide specific benefits to human beings.

Floodplain- low-lying land adjacent to a river or stream bed

Groundwater- water occurring in the zone of saturation in an aquifer or soil (Ward and Trimble 2003)

Infiltration- the downward entry of water through the soil surface into the soil (Ward and Trimble 2003)

Low Impact Design (LID) - is an ecosystem-based approach that aims to integrate development into the ecosystem, instead of removing ecosystems (The Low Impact Development Center, Inc. 2010)

Retention- precipitation on an area that does not escape as runoff (Ward and Trimble 2003)

Stormwater/ Floodwater- the volume of water associated with a precipitation event

Total Maximum Daily Loads (TMDL) - describes the maximum concentration of a pollutant to still achieve water quality standards

Watershed-all of the land area associated with drainage to a specific location.

Abstract

Human development has altered many rivers around the world. In the past, urban rivers were condemned as flood hazards, and load-reducing treatments were the only treatments applied to protect the surrounding communities against flooding. These treatments aim to collect precipitation from the surrounding surfaces quickly and divert the water using the most direct and spatially conservative means as possible- most often using concrete. These treatments have left rivers in ecologically non-functioning states. The channelization of the Los Angeles River in 1938 is a prime example of load-reducing treatment application. This river is unique because it has many constraints of urbanization and is located in a Mediterranean climate, resulting in water availability complications. Completed river projects in Mediterranean climates are presented and the lessons learned from these treatments are applied to the Los Angeles River. Alternative urban river restoration treatments have been successful at using flow-regime management, to return many ecosystem services to riparian ecosystems. Additional objectives were to compare 1.) costs and 2.) ecosystem service restoration success between eight main on-site and eight off-site alternative treatments applicable to urban rivers. Restoration success was evaluated based on the likelihood of restoring ecosystem services (goods and services that benefit humans) related to water quality and hydrologic regime. Due to physical urbanization constraints, the Los Angeles River will never become completely restored. However, this study found that specific reaches within the watershed can be restored to provide natural hydrologic function, retention, infiltration, filtration of water, and natural habitat for the watershed.

1.0 Introduction

Since the development of large cities, starting with the Romans and the creation of aqueducts, urban streams have been straightened, channelized and encased in concrete for human flood protection and development. These storm management actions decrease the ability for water to infiltrate the soil, to naturally flood, transport sediment downstream, to filter pollutants and sediment out of the water column, and allow vegetation to uptake metals and toxins. Urban restoration is important because it recreates the natural hydrology, the movement and distribution of water, of a river and improves water quality for the natural environment. Urban restoration takes a river that is a concrete, channelized, storm drain and returns strategic reaches to its natural purpose: providing clean water to the surrounding environment. River restoration can enhance different ecosystem services such as: water quality, flood protection, pollution control, erosion control, biodiversity, nutrient cycling, and recreation. The determination of the success of a river restoration is based upon the ecosystem services that are enhanced or restored. It is usually not viable to fully restore an urban river to its natural state; however certain services can be restored and enhanced, usually referred to as ecosystem rehabilitation (Findlay and Taylor 2006). Restoration in this paper is defined as ecosystem rehabilitation since urban rivers cannot be fully restored, but ecosystem services and functions can be rehabilitated.

1.1 Urbanization

Urban rivers differ from ‘degraded’ or polluted rivers because of the physical constraints of urban development. Floodplains have been used for human development causing a loss to the natural sinuosity and flood regime. Furthermore, an increase in impervious surfaces produces an unnaturally fast and large volume of water during storm events. An urban river is defined by the amount of developed land within a watershed; if ten percent or more of the land area is developed, a river is classified as ‘urban’ (Findlay and Taylor 2006, Center for Watershed Protection, Inc and Biohabitats Inc. 2007). The increased amount of impervious surfaces alters the hydrologic regime by increasing peak flows and overall volume, decreasing the natural recharge to groundwater aquifers, and affecting water quality by increasing the amount of pollutants within the water supply (He and Hogue 2011). The larger the quantity of urbanized land residing within a watershed, the more degraded the water quality. Based on a study using a general watershed planning model, Impervious Cover Model (ICM), a watershed with 25%

development is expected to be severely degraded in terms of functionality and habitat (Center for Watershed Protection, Inc and Biohabitats Inc. 2007). Physical changes to the landscape, due to development, may seem like small changes to runoff and infiltration; however the compounding effects can be detrimental to many people that rely on clean water from the watershed. Table 1 below, is a summary of additional impacts of urbanization and impervious surfaces can have on riverine ecosystems (Center for Watershed Protection 1998).

Table 1. Twenty impacts of urbanization and impervious surfaces on riverine ecosystems (Center for Watershed Protection 1998).

1. Higher peak discharge rates and greater flooding	11. Decline in stream bed quality (imbedding, sediment deposition, turnover)
2. More frequent bankfull flooding	12. Fragmentation of the riparian forest corridor
3. Lower stream flow during dry weather	13. Warmer stream temperatures
4. Enlargement of the stream channel	14. Greater loads of stormwater pollutants
5. Greater streambank erosion	15. Bacterial levels that exceed recreational contact standards
6. Increased alteration of natural stream channels	16. Lower diversity of aquatic insects and freshwater mussels
7. Less large woody debris (LWD) in streams	17. Lower diversity of native fish species
8. Loss of pool and riffle structure	18. Loss of sensitive fish species (e.g., trout, salmon)
9. Increased number of stream crossings, with greater potential to affect fish passage	19. Lower spawning success of anadromous fish
10. Degradation of stream habitat structure	20. Decline in wetland plant and animal diversity

The degradation of riverine (river) habitat and the addition of pesticide and pollutant use directly decrease river water quality. Despite standard water treatment, pharmaceutical compounds from human use have been found in urban rivers (Bernhardt and Palmer 2007). This input is an additional, urban-specific, complication in water quality that is not a concern in rural areas. Chemical water quality parameters that are affected include increased amounts of: oxygen demand levels, conductivity, suspended solids, ammonium, hydrocarbons, nutrients, metals and toxins (Everard and Moggridge 2012). Healthy riparian ecosystems can act as a filter for water in-stream, as well as collect toxins that are washed off impervious surfaces. When riparian areas are degraded, they lose their ability to filter pollutants and sediment. Pesticides are another major source of urban water pollution. Residential and commercial pesticides used in urban settings are transported in stormwater runoff to nearby waterways. Pesticides can bind to sediment and

accumulate in the bottom/sediment layer of rivers or remain suspended in the water column. The presence of pesticides within waterways can impair aquatic life if it is present in high enough concentrations (Ruby 2013). The chemical quality of water is highly affected by inputs from human lifestyle and the surrounding urban environment.

In addition to decreasing water quantity and quality, urbanization of watersheds decreases riverine ecosystem habitat for native plants and animals to live and thrive. Walsh et al. (2005a) describes the problem of “Urban Stream Syndrome”, a decrease in the richness and diversity of native plant, animal and fish species and an increase in non-native and pollutant tolerant species (Everard and Moggridge 2012, Giller and Malmqvist 1998, Bernhardt and Palmer 2007). Development of river systems and habitat loss in urbanized watersheds result in unsustainable habitats for native biota, which are the foundations of functional riverine ecosystem.

1.2 Urban River Restoration

The main concern of urban river restoration when utilizing the information from a river’s hydrograph is to rehabilitate the range of flows (Clifford 2007) and to level out the peak of storm events. A hydrograph is a representation of the unique flow rate of a stream in terms of time (Trimble and Ward 2003, Clifford 2007). The increased impervious surfaces of urbanization change a natural hydrograph that is characterized by a longer time lag with a gradual peak flow to having a shorter time lag with higher peak flows and reduced baseflows. (Bernhardt and Palmer 2007), as seen in Figure 1. The higher peak flows is characteristic of flash flooding, while reduced baseflows resemble less water in river beds. Restoring the variability will enhance the hydrologic functions of the river and decrease the destruction of storm events.

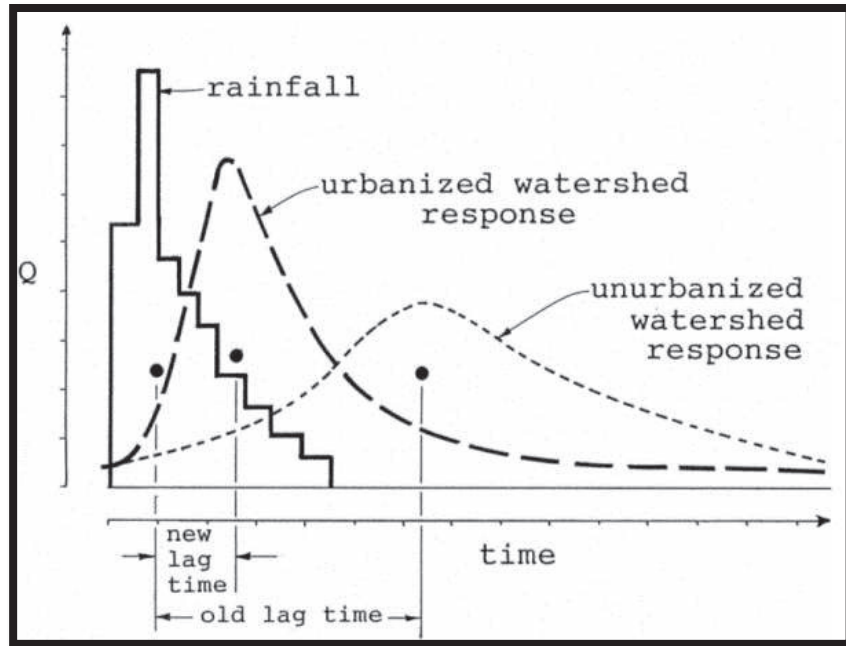


Figure 1. A river hydrograph depicting the differences in lag times of urban and unurbanized watersheds, shown by the black dots. The urbanized watershed has a flashy and shortened time lag (dashed line) compared to the longer, less drastic time lag of the unurbanized watershed response (dotted line) (Rogers J.D 1997).

Storm management, (focuses on load-reducing efforts) changes the normal hydrology of rivers, making it difficult to maintain natural hydrologic processes- the movement of water by infiltration, retention, meandering, and sediment transportation. Urban rivers are typically more fragmented and have more drastic slope features and cross sections (Clifford 2007), the opposite of natural river characteristics. An urban river is augmented with ‘hardened’ streambanks by engineered boulders and riprap to prevent erosion. This hardening decreases streambank erosion but has constrained stream channel movement and evolution and added to scouring, erosion in the depth, of the channel (Bernhardt and Palmer 2007).

The physical constraints of urbanization and urban/industrial runoff provide major obstacles in restoring the functionality of the stream hydrology and water quality to urban rivers. Additionally, the high costs of these projects and numerous stakeholder agendas create other difficult obstacles. It is more costly to restore urban rivers because of the high cost of adjacent

land. This makes it more expensive to purchase the sufficient acreage for floodplain restoration (Bernhardt and Palmer 2007), decreasing the effectiveness of restoration.

Despite these obstacles, there are opportunities in less developed reaches where levees can be setback, concrete can be removed from stream beds, bioengineering techniques can filter urban runoff and stabilize banks, and riparian habitat can be created. Urbanization increases runoff from impervious surfaces which provide the opportunity for stormwater harvesting and consumption (Ward and Trimble 2003). By infiltrating precipitation runoff throughout the watershed, it will decrease the likelihood of flooding during storm events, by decreasing the runoff volume.

The most important opportunity associated with urban river restoration is the direct involvement and support of the surrounding communities' residents. Because there is a large population, residents can assist with on-site restoration including clean-up, weeding and planting. Rural restoration sites do not have this benefit. In addition, they can implement off-site restoration treatments to improve watershed health. These off-site treatments, described in section 5.2.2, provide natural water filtration, decrease stormwater loads, and increase pollutant uptake before runoff enters the riverbed. Off-site treatments treat and control the water at the source, using natural methods. Application of treatments in the upper watershed contributes to the on-site restoration efforts downstream. Urban restoration has many obstacles but can be transformed into opportunities of water quantity and quality functioning.

There are a variety of effective treatments for river restoration available depending on the location, ecosystem services restored, and cost. On-site restoration treatments include setting back levees, diverting storm drain runoff, widening the floodplain, constructing detention ponds, and creating sinuosity through placement of physical hydraulic control structures in the stream via a hydraulic control structure (Ward and Trimble 2003). On-site projects generally cost more than off-site treatments, due to major construction-based, labor-intensive actions and less community involvement. Off-site projects are generally less expensive, but do not directly enhance as much water quality or hydrologic regime as on-site projects. There are a range of cost and effectiveness tradeoffs between on- and off-site treatments, seen in Table 4 & Table 5.

Urban river restoration efforts have become more widespread and successful in recent years. Examples of successful urban river restoration projects where greenways were created for recreation include the South Platte River in Denver, CO, the Ohio River in Cincinnati and the Willamette River in Portland, OR (Gumprecht 2001). The Chicago River was once heavily contaminated with raw sewage. After regulating the Total Maximum Daily Load (TMDL) inputs and implementing water quality restoration, groups of people have begun to swim in it daily and fish populations have increased by a factor of four (Gumprecht 2001). The Paseo del Rio completed restoration in 1941 in San Antonio, Texas. It is the oldest example of river restoration that incorporated recreation, leisure (an amphitheater) and business opportunities along the river (Gumprecht 2001). In South London, on the River Quaggy, a concrete channel was replaced by a functional floodplain and areas for recreation. The River Quaggy restoration created an impressive overall lifetime benefit to cost ratio of 7:1 (Everard and Moggridge 2012). These past projects and many others have shown successful implementation of urban river restoration for a variety of goals and enhancements of ecosystem services.

1.3 Ecosystem Services

Ecosystem services are the goods and services that the environment provides to humans. Table 2 below highlights the ecosystem services that non-altered river and riparian ecosystems provide based upon the Millennium Ecosystem Assessment (Mooney et al. 2005b). Urban river restoration enhances provisioning ecosystem services, regulating services, supporting ecosystem services, and incorporates cultural services (Mooney et al. 2005a).

Table 2. Ecosystem services provided by non-altered rivers (derived from Mooney et al. 2005b)

Ecosystem service	Examples and definitions	Type of enhancement based on river feature
Provisioning Services	<ul style="list-style-type: none"> -Fresh water storage and retention; used for drinking and irrigation -Food: fish, fruits, grains, or game -Fiber and fuel: timber, peat, or fodder 	<ul style="list-style-type: none"> - Permanent or seasonal river -Seasonal vegetated floodplains -Groundwater recharge
Regulating Services	<ul style="list-style-type: none"> -Hydrological regimes -Pollution control -Detoxification -Flood protection -Erosion control 	<ul style="list-style-type: none"> -Permanent or seasonal river -Seasonal vegetated floodplains -Groundwater recharge (detoxification)
Supporting Services	<ul style="list-style-type: none"> -Biodiversity: habitats for species -Soil formation: organic matter retention and accumulation -Nutrient Cycling: storage, recycling and processing 	<ul style="list-style-type: none"> -Permanent or seasonal river -Seasonal vegetated floodplains
Cultural Services	<ul style="list-style-type: none"> -Inspirational or spiritual: well-being and personal or religious significance -Recreation: tourism and activities -Aesthetics: natural feature appreciation -Education: informal and formal education and training 	<ul style="list-style-type: none"> -Permanent or seasonal river -Seasonal vegetated floodplains

This paper focuses on two of the four categories of ecosystem services provided by ecosystems: regulating and provisioning services. Accessibility to clean water is both provisioning and regulating for humans. Clean water is the basis of all ecosystems which is why restoration of water quality is the most important feature. Based on global freshwater, much of the runoff in urbanized watersheds is not successfully collected. Urbanized areas only capture

0.2% of the available freshwater from runoff. This water capture is supposed to sustain a population of 4.5 – 5 billion people (Mooney et al. 2005a). Runoff, when cultivated, has the ability to increase freshwater capture by 16% (Mooney et al. 2005a). Restoration treatments along urbanized rivers have the ability to increase the quantity of water that is retained and available for human and ecosystem use, increasing the sustainability of the surrounding development.

Natural riverine habitats provide regulating services of natural hydrologic regimes, flood abatement, erosion control, and filtration of contaminants. The hydrologic regime of rivers includes the flows and interactions of water within a system including the interactions of: precipitation, runoff, evaporation, terrain, climate, groundwater, and surface water. Flood management prevents precipitation from accumulating and flooding the communities surrounding the river. Flooding causes increased sediment input and accumulation from bank erosion; decreasing water quality, bank stability, and quality of ecosystem habitat. Restoring the riparian and wetland habitats on the river will combat and even reverse the issues of sedimentation and erosion from flooding. Many pollutants and contaminants can be assimilated by riparian vegetation and/or buried in the sediment, removing it from the water column. Restoration of habitat can create natural water infiltration and recharge groundwater aquifers from the surrounding environment.

1.4 Hypothesis

This Master's Project discusses the different treatments of urban river restoration in regards to restoration proposed on the Los Angeles River. This synthesis will assist a variety of audiences understand multi-approach treatments to improving a degraded, urbanized river. I present summaries of treatments including comparisons of the three criteria: location, cost and success of ecosystem service restoration. Each of the 18 treatments, were evaluated for success defined by the enhancement or creation of ecosystem services. A number of successful urban river restoration projects in the Mediterranean climate of California were compared and contrasted to the current constraints and opportunities on the Los Angeles River. Projects evaluated include those along the Santa Ana River, the San Joaquin River, the Guadalupe River, Thompson Reach of Tennessee Hollow Creek in the Presidio of San Francisco, and Calleguas Creek. The main goal of this paper was to determine the effectiveness of off-site and on-site

urban river restoration treatments on the LA River and how to best implement each type to maximize the benefits of each treatment. This paper presents a guide to successful urban river restoration of ecosystem functions along the Los Angeles River through effectively utilizing the many potential on-site and off-site treatments, and understanding the opportunities and obstacles of past urban river restoration projects.

2.0 Background of the Los Angeles River

The Los Angeles River (LAR) located in Southern California, begins near the city of Calabasas at an elevation of 795 feet above sea level, and flows approximately 51 miles into the Pacific Ocean at San Pedro Bay (The River Project 2013). As seen in Figure 2, the watershed of the LA River covers 834 square miles and encompasses 44 cities, supporting a population of 9 million people. The LAR is characterized by intermittent flow throughout most of its course, and ephemeral flow in parts of the upper watershed (Trimble and Ward 2004). The average seasonal rainfall for Downtown LA is 14.77 inches (National Oceanic and Atmospheric Administration 2014). There is not an “average” flow for the LA River due to highly variable precipitation patterns; however peak flow has been recorded at 183,000 cfs (cubic feet per second). This peak flow is 14 times faster than the peak flow of the Hudson River in New York (The River Project 2013). The Los Angeles River is an important source of freshwater that is underutilized.

The LA River is affected by a variety of stakeholders. The watershed is comprised of the following land uses: residential (37%), open space (44%), and commercial and industrial covering less than 20% of the watershed (LA District 2013). In addition to the surrounding residents, there are over 13 municipalities that share adjacent land, rights, responsibility and interests in the LA River’s health, as well as federal, state, county, and utility companies. The US Army Corps of Engineers (USACE) and the Los Angeles County Department of Public Works (LACDPW), Flood Control District shares the flood maintenance responsibilities for the LA River (Country of Los Angeles Department of Public Works 2004). Additionally, there are three wastewater treatment facilities that discharge into the river: Tillman Water Reclamation Plant in Los Angeles, Water Reclamation Plant in Burbank, and the Glendale Water Reclamation Plant in Los Angeles. These stakeholders must collaborate and communicate to successfully restore the Los Angeles River.

2.1 History of the Los Angeles River

The river was the exclusive freshwater source for the residents of Los Angeles until 1913, when the LA River aqueduct was completed and transported water from the Owens River to Southern California. In 1920, Devils Dam was erected and connected to the LA River for groundwater recharge and water storage. This interrupted the important river flow-regime as well as nutrient and sediment transportation downstream. Severe flooding from 1934-1938 damaged over \$23 million worth of property and killed 85 individuals. As a result, the USACE channelized the majority of the river and lined the channel with concrete between 1938 and 1959. After, the river was considered a glorified storm drain until the 1990s when the former-mayor of Los Angeles, Tom Bradley, initiated a River Revitalization task force (Los Angeles County 2007). The task force was given 10 objectives focused on 1.) restoration of natural habitat 2.) maintenance and enhancement of flood protection and 3.) fostering of sustainable practices (LAR-RMP-amended 10/8/2002). In 2007, the LA River Revitalization Master Plan modeled a potential 32-mile stretch of greenway plan through downtown LA (FoLAR and Los Angeles County Department of Public Works 2006). River restoration has recently gained fundamental support for several sections of the river.



Figure 2. Map of the Los Angeles watershed. The LA River is outlined with a thick blue line and the smaller blue lines represent the confluence of other smaller streams in the watershed. (Photo Source: Wikipedia-Los Angeles River)

2.2 Supporting River Restoration Legislation

The Federal Clean Water Act (CWA) is the primary protection legislation for the Los Angeles River. The CWA (1972) was created to ‘restore and maintain the chemical, physical, and biological integrity of the nation’s rivers’ (Giller and Malmqvist 1999). The CWA’s jurisdiction protects navigable waterways-“all waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide” (USACE Appendix D). Several Supreme Court cases have questioned the USACE and United States Environmental Protection Agency (USEPA)’s jurisdiction of many rivers, streams, and adjacent wetlands in the arid west since they do not flow year round, including the LA River. However, a court decision from the Rapanos case in 2006 defined jurisdiction of the CWA as including ‘non-navigable tributaries’ that are Relatively Permanent Waters (RPW). This includes perennial and intermittent streams that have continuous seasonal flow (Wickens and Monarres). The CWA enables the LA River to be funded and protected by direct jurisdiction of the USEPA and the USACE against pollution that is unhealthy to human and recreational standards.

The CWA have set specific regulated standards of water quality that have been proven safe levels for humans, habitats, and wildlife. Section 303 of the Clean Water Act requires set water quality standards and TMDLs for pollutants that permit aquatic life and allow for swimming and fishing within the water (United States Environmental Protection Agency 2012). Section 404 of the CWA gives the USEPA and USACE jurisdiction to dredge and fill in Waters of the US. This section protects the wetland ecosystem habitats in and adjacent to the stream.

In addition to protection under the CWA, there is federal and state legislation that protects and funds the restoration of the Los Angeles River. In 2004 and 2006 Proposition O and Proposition 84 were passed. These supplied a \$500 million and \$5.4 billion bond for projects to protect against flooding and enhance water quality resources for the environment and for safe drinking, specifically looking at TMDL requirements (TreePeople 2007, Park, Pincetl and Stenstrom 2008). According to Section 438 of the federal Energy Independence and Security Act (2007), government agencies are required to use green or Low Impact Development (LID) treatments on new or retrofitted construction projects to decrease stormwater and flooding risk in the United States (United States Environmental Protection Agency 2013). LID is an ecosystem-

based approach that aims to integrate development into the ecosystem, instead of removing ecosystems (The Low Impact Development Center, Inc. 2010). The CWA protection created a major opportunity that supported the LA River's future restoration (Pacific Legal Foundation 2008).

2.3 Los Angeles' Mediterranean-Type Climate

A major constraint of restoration for the LA River restoration is the water-stressed climate. The LA River is located within a semi-arid, Mediterranean-type climate in coastal California. Downtown LA's annual average high temperature is 75°F with an annual low average of 57°F (National Oceanic and Atmospheric Administration 2014). Location within a semi-arid and Mediterranean-type climate equate to highly seasonal and variable amounts of precipitation throughout the year (Kondolf 1998). This high variability enhances the effects of fluvial geomorphology of a riverine ecosystem- the shaping or formation of the land by the interaction with water (Trimble and Ward 2003, Clifford 2007). The fluvial geomorphology is important because it connects the river with resources laterally, vertically and downstream (Clifford 2007).

The channel size and path of the LA River in its natural state varies from year to year because of variation in precipitation- one year may produce a small narrow channel and other years a wide flood plain. Because of this variation, it is important to understand the fluvial geomorphic and ecological processes specific to the watershed to ensure the success of the restoration. Many restoration treatments have failed because of an oversight of understanding the fluvial geomorphology of a river. For example, low flows or large floods as a result of variable precipitation patterns can destroy or impair new treatments. In normal, Mediterranean-type climate river restorations, a portion of the river corridor is set aside to allow for the river to create complex geomorphology and habitats, known as the 'channel migration zone' (Kondolf, Podolak, and Grantham 2012). This approach is not a feasible restoration treatment on the LA River due to developed land use constraints. Despite the constraints of a Mediterranean-type climate, the LA River can be restored to function naturally to provide clean water and mitigate the detrimental inputs from urbanization.

2.4 The Current Los Angeles River

The Los Angeles River is an iconic water way that has been fundamentally altered by humans over the past century. It is an opportunity to showcase and publicize the benefits of

urban river restoration, the ecosystem services it can enhance, and the beneficial effects it can have on water quality and flood abatement. Restoring functional riparian habitats and hydrology on the LA River will be difficult since a majority of the lower floodplains have been lost to urban development. The majority of the river's once uncontrolled, meandering channel is now constricted by the direct proximity to urbanization. Conventional riparian restoration efforts, such as revegetation, may create additional flood risks to surrounding communities. Despite the obstacles presented by urbanization, there have already been successful small-scale restoration projects on the LA River. These projects include the Dominguez Wetland Gap (a 50-acre wetland), and the Tujunga Greenway (1.6 miles of the stream channel restoration) (LA County DPW). An ecosystem feasibility study conducted on the LA River found eight possible sites for restoration along an 11.5 mile reach of the river. The sites are located from the 'Headworks' area to First Street in downtown LA (LA District 2013). Additional restoration possibilities are feasible at the confluences of waters joining the LA River and at the few open spaces, for example: Sepulveda Basin, Sepulveda Dam to Tujunga Wash, Tujunga Wash to the Spreading Grounds, and the Cornfields-Chinatown area to 1st Street.

2.5 Restoration Opportunities and Obstacles

The two major obstacles that overarch all restoration planning are the Mediterranean-type climate and urbanization factors. These obstacles specifically decrease groundwater infiltration into soil and increase frequency and volume of flooding.

The Mediterranean-type climate has the unique stress of a highly variable and extreme water input. Rivers in semi-arid environments are more sensitive to urbanization and have hydrologic and water supply complications (He and Hogue 2011). These river characteristics include: a long dry season with minimal flow (except for input from runoff or wastewater plant input) are contrasted with limited torrential storm events during the winter/spring months. Runoff from these storms can reach velocities up to 45 miles per hour (Mount 1995, Everest International Consultants, Inc. 2002). The high flow storm events can destroy habitat as well as carry dangerously large pieces of debris at high velocities (Everest International Consultants, Inc. 2002). Annual runoff varies from 4m³/sec during the dry-season to 236 million m³/year during the wet season (Park, Pincetl and Stenstrom 2008). To ensure successful and sustainable

restoration, periodic storm events need to be considered in congruence with low flow periods when planning the creation of habitat and floodplains.

Physical constraints are a major obstacle for urban river restoration. Utility objects like oil and gas pipes, electrical transmissions, transportation, sewers, and telecommunication lines can be in the way of restoration planning (Everest International Consultants, Inc. 2002). These obstacles are not only physical constraints to restoration, but additional costs if these items need to be re-routed or removed.

Urbanization intensifies the stress of a Mediterranean river ecosystem because of anthropogenic physical and biological inputs. Increased urban development adds to the stress of Mediterranean-type climates by concentrating contaminants, algae, and plants in the waterway. These factors, coupled with higher temperatures from non-natural surfaces decrease dissolved oxygen levels making areas inhabitable by plants and animals (Cooper et al. 2013). Climate change is predicted to further increase stress by increasing the variability of the weather and creating hotter, drier temperatures (Cooper et al. 2013).

Urban restoration is more costly because of increased land use values per capita in addition to factoring removal of engineered infrastructure. As stated previously, the urban and industrial physical constraints make any construction costly. Treatments such as levee setback and removal and connecting the river with ground water will be very costly because of labor intensive removal and disposal. Additionally, the land surrounding the river has a higher capita per square foot because of demand for development. The only feasible areas for floodplain restoration are degraded, vacant areas or land that is currently owned by the city.

The obstacle of increasing water quality is specifically important to the eastern cities of the San Fernando Valley area because four sites have been sanctioned as superfund sites by the EPA: Burbank/North Hollywood, Glendale/Crystal Springs, Verdugo and Pollock/Los Angeles (United States Environmental Protection Agency 2009). Some of the superfund sites' boundaries are shared with the LA River. All four sites are within the Los Angeles watershed and have degraded groundwater quality to the point of closing several ground water wells and forcing the cities to purchase their water from elsewhere. The types of contaminants include metals, oxidizers and VOCs (volatile organic compounds) (United States Environmental Protection

Agency 2009). This added level of degradation is an obstacle for groundwater remediation and adds complexity and cost to the areas that convene on the LA River. Despite this obstacle, the remediation offers the opportunity to drastically increase groundwater and improve surface water quality. It also will be especially important to the surrounding community to have a healthy source of water.

Despite the physical, climatic and funding obstacles, there are many opportunities associated with restoring the LA River. Now is a favorable time to restore the Los Angeles River because the flood management infrastructure in place can no longer support the demands of the river, it needs to be replaced. Significant funding and planning efforts need to happen regardless of the desire to restore the river (The River Project 2013). River restoration is a sustainable approach that provides the same functions as the current engineered treatments in place while enhancing the ecosystem services a natural river can provide. Implementing restoration treatments addresses and fixes the causes of flooding, whereas engineered stormwater management approaches will only fix the symptoms and need to be replaced repeatedly.

An opportunity available to restoration along the LA River is the formation of the Los Angeles River Watershed Monitoring Program (LAR-WMP). The LAR-WMP synthesized five years of baseline monitoring data within the LA River. The LAR-WMP's findings determined that the riparian habitats within the upper LA River watershed were less impacted than the degraded downstream areas. Three publicly-owned treatment works (POTWs)-Tillman Water Reclamation Plant, Water Reclamation Plant, and Glendale Water Reclamation Plant- have a 'net-positive' effect on downstream water quality (Council for Watershed Health 2007). The concentrations from POTW's input of dissolved metals, bacteria (such as *E. coli*), and suspended solids are lower than in the river itself (Council for Watershed Health 2007). Additionally, these POTWs provide the river with a stable baseflow during the dry season (Everest International Consultants, Inc. 2002) making up approximately 70% of the flow in the summer and 40% in the winter months (Karimi, Redman and Ruiz 1998). It is encouraging that the inputs from POTWs are not degrading the river water quality; however, this added input changes historic river flow patterns.

To determine if the water quality in the LA River is suitable for swimming, LAR-WMP monitored similar Southern California river recreation sites. Both the monitored sites and the LA

River had increased levels of bacteria during summer months. Further monitoring will be conducted to determine correlation of increased events. Compared to California fish populations in other rivers, fish in the LA River had surprisingly lower concentrations of mercury, and comparable concentrations of selenium, Dichlorodiphenyltrichloroethane (DDT), and Polychlorinated biphenyls (PCB) (Council for Watershed Health 2007). Restoration planning can utilize these monitoring results to best enhance the opportunities available on the LA River.

Groundwater recharge is a sustainable water conservation opportunity to increase watershed health. Frequent flood events, when planned for accordingly, can be an opportunity for groundwater recharge and natural river floodplain maintenance (Guivetchi 2014). Mediterranean-type climates face significant water scarcity, exacerbated by urbanization and channelization that discard the scarce amount of precipitation. The groundwater capacity of the San Fernando, Central, and West Coast basins are underutilized and have the potential to increase drinking water supply (The River Project 2013). Diverting storm runoff to groundwater aquifers will decrease the risk of flooding while increasing the sustainability of Los Angeles' freshwater supply.

Small changes in groundwater infiltration, creates a significant difference in available water supply, especially in arid climates which heavily rely upon groundwater resources. A Hydrologic Simulation Program Fortran (HSPF) model examined groundwater recharge loss from urbanization in the Los Angeles watershed. He and Hogue (2011) calculated an average loss of infiltration of 0.67mm/year (best case scenario) to 3.96mm/year (worst case scenario). These infiltration reductions equate to a household water disparity for an estimated 600 to 3,400 people respectively (He and Hogue 2011).

Furthermore, cultivation of community support will develop opportunities to implement and expand education of the LA River restoration. The non-profits organizations, Friends of the Los Angeles River (FoLAR), Paddle the LA River, The River Project and TreePeople are examples of community and educational organizations that promote urban river restoration. The organizations have created clean up days and educational workshops for residents, as well as highlighted available off-site residential and commercial restoration treatments.

3.0 Methods

In this Master's Project, I reviewed federal, city, state, and agency reports along with project documents focused on monitoring data, water quality data, feasibility reports, and projected restoration. Additionally, I gathered information about off-site restoration projects from the websites and publications of nonprofit organizations such as TreePeople, Council for Watershed Health, and The River Project. The Millennium Ecosystem Assessment (Mooney et al. 2005b) was utilized to determine the ecosystem services provided by the Los Angeles River. For the purpose of this study, I focused on the restoration of provisioning services- freshwater (storage and retention), as well as regulating services- hydrologic regimes, pollution control, detoxification, flood protection, and erosion control. Provisioning and regulating services are the most important components to restoring the functioning processes to the river flow, the seasonal vegetated floodplain and groundwater recharge. Additionally, I recognized the treatments that restore habitat and recreation, but did not analyze this data further. I evaluated peer-reviewed literature to understand the obstacles and opportunities of urban rivers in Mediterranean-type climates. I conducted interviews with Edith de Guzman (Director of Research at TreePeople), Melanie Winter (Director of The River Project), and Eileen Alduenda (Council for Watershed Health) to discuss past and future implementation projects and monitoring of off-site restorations in the upper Los Angeles River watershed. Furthermore, I had email correspondence with Eileen Fanelli, (Environmental Remediation Program Manager at the Presidio Trust) and Terri Thomas, (Director of Conservation, Stewardship and Research at the Presidio Trust) regarding monitoring and post-project reports from Thompson Reach restoration.

Through my research, I discovered a lack of synthesized, long-term monitoring data for urban river restoration, including the Los Angeles River. Much of the data found was raw data compiled by government agencies for budget reporting purposes. I found it difficult to assess success of restoration due to lack of monitoring or reporting data. As a result, success presented in this project is 'predicted success' unless stated otherwise. Moreover, many public reports available for urban river restoration sites were too general and lacked final reports regarding the practical treatments taken.

4.0 Assessment of Restoration Projects on Mediterranean Rivers

Five urban river restoration projects in Mediterranean-type climates were assessed based upon the treatments used, the cost and the enhancement of ecosystem services (Table 3). The rivers evaluated were: the Santa Ana River, the Guadalupe River, the San Joaquin River, Thompson Reach and Calleguas Creek. These rivers do not exactly match the opportunities and obstacles of the LA River. However, the lessons learned from each of these river restorations offer invaluable information to use during restoration planning. Assessing the past projects will ensure that mistakes are not duplicated on the Los Angeles River.

4.1 The Santa Ana River

The Santa Ana River is an example of what the Los Angeles River would look like if it had not been channelized- both were naturally braided stream systems in a Mediterranean climate. The Santa Ana River is located in Southern California and spans 2,600 square miles. It begins at an elevation of 11,500 feet in the San Bernardino Mountains, flows through Los Angeles, Riverside, San Bernardino and Orange counties and ends in the Pacific Ocean at Huntington Beach (Santa Ana Watershed Association 2012). The Santa Ana Watershed Association (SAWA) was developed in 1995 in association with the USACE, U.S. Fish and Wildlife Service (USFWS), California Department of Fish and Wildlife (CDFW), and the Regional Water Quality Control Board (RWQCB). The SAWA is a non-profit organization that's goal is to restore the health of the Santa Ana watershed. The main focus of restoration for the Santa Ana River is removing 500 acres of invasive species, *Arundo* (*Arundo donax*) and *tamarisk* (*Tamarix* spp.) in addition to other invasive plant species (Santa Ana Watershed Association 2012).

Arundo is a non-native plant that is extremely aggressive and out-competes local vegetation. It acts as a natural barrier in the streambed during storm events, impacting the surrounding native habitat (Arechavaleta 2009). In terms of cost, a two-year removal project of 50 acres (CCIP1) cost approximately \$313,000 for removal work and contractor fees (Santa Ana Watershed Association 2012). As of 2012, efforts by SAWA have successfully removed about 4,500 acres of invasive plants from the watershed (Santa Ana Watershed Association 2012).

Other alterations made to the Santa Ana River that have impacted biodiversity include channelization and man-made levees. The 2009 Levee Report examined the effects of

channelization and man-made levees and recorded significantly reduced abundance of bird species (Arechavaleta 2009). Although the Santa Ana River has less channelization than the LA River, there is still a decrease in biodiversity near engineered infrastructure.

Compared to the LA River, the Santa Ana River is less urbanized. Only 45% of the watershed is covered by urban, farm or pasture land uses with a population density of 673/ km² (Cooper et al. 2013). The LA River does not have as much acreage to restore in terms of invasive plant removal due to the physical constraints of urbanization.

Restoring native plant communities not only enhance habitat but also support natural hydrologic regime and improve water quality. Hydrologic regime is supported by the ability of the land to retain and filter the available water supply. The native riparian habitat and wetland area act as sponges and retain a large amount of stormwater. The native plant community also filters pollutants, metals and sediment out of the water, improving surface water quality. This filtration process occurs for water that is infiltrated into the groundwater as well. Restoring native plant communities not only improves surface and groundwater quality, but also restores the ecosystem services associated with improving habitat, flood abatement, erosion control, and recreation.

4.2 The Guadalupe River

The Guadalupe River is located in Northern California in the Guadalupe Creek Watershed that runs through the cities of San Jose, Los Gatos, Monte Sereno, Campbell, and Santa Clara. Due to severe damages from flooding, bypass channels were created to aid in flood protection in addition to restoring several reaches of the river (Santa Clara Valley Water District. 2014). The river is the source of water for the San Jose River Park and Gardens, the ‘Central Park’ of San Jose. In 2005, the downtown reach was restored for \$340 million. The restoration provided flood control for up to 17,000 cfs (equivalent to a 100-year flood event), as well as created recreational terraces for citizens to utilize. The bypass network allows natural habitat to survive and prevents the river channel from overflowing in high flood events (Oakland Museum of California 2014).

The LA River and the Guadalupe River are similar in that both are located within a Mediterranean-type climate, constricted by a dam and stormwater runoff for flow inputs, and

have extensive inputs of urbanization in specific reaches. As discussed above, the hydrograph for the Guadalupe River shows decreased runoff in the summer months with baseflow relying heavily on the winter and spring rainfall. In contrast to the LA River watershed, the Guadalupe River watershed is considerably smaller and extremely less urbanized; it occupies only 170 square miles with less than 8% urbanized land use (Santa Clara Valley Water District 2014). Only 500 feet of the length of the river are completely concreted, the majority of the river has an earthen bed (Santa Clara Valley Water District 2014). The Guadalupe River restoration is a smaller scale representation of on-site restoration treatments currently proposed for the Los Angeles River.

The objectives of the past Guadalupe River restoration were threefold: to create a healthy salmon spawning and migration habitat, to create a river walk, and to provide floodwater storage (Santa Clara Valley Water District 2014). The Guadalupe River treatments included: creation of flood zone terraces, demolition of buildings within the flood zone; improvement of the natural capacity of the channel; setback of current levees to allow a wider flood plain; non-native species removal and native habitat creation for shade and water temperature stabilization; and removal of contaminated, compacted soil for flood control remediation (American Society of Landscape Architects and Water Rock Construction 2014). These actions were taken in the hopes of restoring the following ecosystem services: habitat, recreation, flood abatement, and water quality.

4.3 The San Joaquin River

The San Joaquin River begins is located in the Central Valley of California, starting in the Sierra Nevada Mountains at an elevation of 9,839 feet and continues for 366 miles, eventually flowing into the San Francisco Bay Delta and out to the Pacific Ocean. Portions of the river were restored after an 18-year lawsuit was settled in 2006 between the United States Department of the Interior and Commerce, the National Resource Defense Council (NRDC) and Friant Water Users Authority (FWUA). The restoration goals of the settlement were aimed at maintaining and supporting fish populations while improving the health of the water supply below Friant Dam to the confluence of the Merced River (San Joaquin River Restoration Program 2011b). This was in response to Friant Dam altering the natural hydrologic regime of the San Joaquin River so drastically that 10 miles of the river completely dried up.

Since a main objective of the restoration was to support anadromous fish populations, the treatments used focus on creation of fish habitat, supplying the necessary water quality, and water flow for fish survival. To create habitat areas for fish, complex structures such as root wads and rock clusters were added to the stream channel (San Joaquin River Restoration Program 2011a). These structures also create “flow divergence and convergence” which leads to pool scouring and sediment sorting- providing crucial spawning habitat for fish species (San Joaquin River Restoration Program 2011a). Boulders and cobbles were added to the stream channel to increase the roughness to encourage fish-friendly flow and habitat (San Joaquin River Restoration Program 2011a). Fish habitat will be created by cutting secondary channels and setting back levees. These actions increased floodplain area, for natural sinuosity, and increased habitat area (San Joaquin River Restoration Program 2011a). Restoration will also address levee repair and flood protection for the surrounding communities. Water quality will be monitored on an ongoing basis with specific focus on salinity levels to determine appropriate flow releases to reduce brackish waters. Although one of the main goals of the Guadalupe River restoration is to increase fish populations, the vegetation associated with fish habitat creation simultaneously improve water quality and in-stream habitat.

There is considerable contrast in the primary restoration objectives between the San Joaquin River and those of the Los Angeles River. As a fore mentioned, the San Joaquin river restoration focused on restoring fish habitat. On the other hand, due to urbanization factors the LA River restoration's principal concern is to provide flood protection and improve infiltration into groundwater aquifers. The San Joaquin’s main input is agricultural runoff and pollution whereas the Los Angeles River is mainly subjected to urban runoff from residential and industrial uses. Both rivers similarly have restrictions from dams in their upstream reaches and they are both influenced by Mediterranean-type climate. The ecosystems services that can be feasibly restored are: habitat, water quality, food services (fisheries), water source, and flood abatement.

4.4 Thompson Reach

Thompson Reach is a section of creek located in the lower portion of the Tennessee Hollow Watershed, also known as El Polin Creek, in the Presidio of San Francisco, California. In 2005, a majority of the creek was ‘daylighted’. Daylighting is a term referring to the redirecting

of a water system into an above ground state. Thompson Reach was brought out of a pipe and above ground, by removing 77,000 tons of concrete, landfill debris and culvert material. Over 35,000 native seedlings from the Presidio Nursery were used to restore the surrounding creek habitat. According to the Presidio Trust, there has been an increase in nesting birds as well as the presence of stickleback fish (Presidio Trust 2013). These biological indicators provide positive information regarding the development of the restoration. Thompson Reach has seven years of compiled monitoring data; however it is not yet used for reporting purposes. Terri Thomas, Director of Conservation, Stewardship and Research at the Presidio Trust, concludes that out of the other restoration sites within the Presidio Trust, Thompson Reach is the ‘farthest along’. Thompson Reach restoration is a successful small-scale example of concrete removal and habitat revegetation. Ecosystem services restored include habitat, water quality, flood protection, and erosion control.

4.5 Calleguas Creek

The Calleguas Creek Watershed is located in Ventura County, California. It originates in the Santa Susana Mountains, at an elevation of 3,700 feet, and runs 30 miles to the Pacific Ocean. It drains approximately 344 square miles. The watershed is within a Mediterranean-type climate with yearly precipitation averages from 21 inches in the mountains to 12 inches on the lower floodplains (David Magney Environmental Consulting Inc. 2000). The past management treatments have utilized engineering treatments such as: trapezoidal-shaped channelization, riprapped banks, underground concrete and pipe culverts (David Magney Environmental Consulting Inc. 2000). These treatments only provide flood protection and do not include any vegetation or alternative designs to incorporate habitat restoration into stormwater protection. Calleguas Creek is degraded from both urbanization in the lower reaches and agricultural land use in the upper reaches of the watershed. The goals of restoration include creation of a riparian buffer utilizing wetlands and bioengineering techniques which also combat streambank erosion, in addition to improving water quality by monitoring TMDL.

Calleguas Creek incorporates a multiple restoration actions to reach the varied goals of stakeholders. Calleguas Creek restoration was initiated by a grant from the US Resources agency due to water quality concerns by nonprofit organizations, governmental and local groups regarding the degradation and loss of wetlands and the symptomatic problems that occurred

because of the loss on the surrounding floodplains (David Magney Environmental Consulting Inc. 2000). The focus of restoration efforts were related to increasing sedimentation, decreasing erosion, providing flood control, improving water quality, and restoring the habitat. The degradation of water quality has directly affected the surrounding community, economically. In 1992, Calleguas Creek was designated by California State Water Resources Control Board as an impaired body of water which is incapable of providing basic water needs to residents due to high levels of PCBs, nitrates and agricultural pesticides (David Magney Environmental Consulting Inc. 2000). The loss of habitat directly impacted the functionality of the river system causing a degradation of the river water quality.

A multidimensional restoration plan was proposed for the Calleguas Creek restoration. Treatments included: hydrology restoration, improved sediment transport, renovation of the physical connectivity of the stream, utilization of vegetation to increase water quality, and restoration of native habitat. Streambank erosion control was a major goal for Calleguas Creek restoration based on the 1995 data from the USDA-NRCS. The findings estimated annual erosion of 152,000 tons of sediment from Calleguas Creek (David Magney Environmental Consulting Inc. 2000). Sedimentation directly degrades river quality; therefore restoration efforts utilized vegetated streambanks. Past restoration projects in braided rivers found that vegetated streambanks eroded 20,000 times less than similar non-vegetated streambanks (David Magney Environmental Consulting Inc. 2000). Additional treatments such as levee removal and setback were implemented. These treatments improved hydrology and reconnected the channel-floodplain which increased stormwater storage, groundwater infiltration, and habitat (David Magney Environmental Consulting Inc. 2000). Furthermore, specific native plants were selected to uptake and capture excess nutrients and provided essential habitat functions.

Table 3. Summary of past restoration projects, the treatments used, and the direct ecosystem services restored.

Restoration Project	Treatments Used	Direct Ecosystem Service Restored
Santa Ana River	-Invasive species removal	-Flood protection -Water quality
Guadalupe River*	-Bypass channels -Recreational terraces -Fish habitat revegetation	-Flood protection -Water quality -Recreation
San Joaquin River*	-Large woody debris -Secondary channels -Water quality monitoring	-Flood protection -Water quality -Erosion control
Thompson Reach*	-Habitat wetlands -‘Daylighting’/concrete removal	-Water quality -Erosion control
Calleugas Creek*	-Levee setback -Bioengineering of streambanks -Wetland restoration	-Flood protection -Erosion control -Water quality

*= habitat restored

4.6 Completed Restoration Projects in Los Angeles Watershed

There are several examples of completed restoration within the LA River watershed: Taylor Yard, Tujunga Wash Greenway (TWG), Dominguez Wetland Gap (DWG), Headworks groundwater Recharge Project (HGROP); as well as off-site projects: the Elmer Avenue neighborhood retrofit, Hall House, Broadous School project in Pacoima (a neighboring watershed), and Open Charter Magnet Elementary. The restoration projects shown in Figure 3 provide a range of restoration possibilities and present successful models to incorporate in future restoration project planning.

The restoration of Taylor Yard, located adjacent to the LA River in Glendale, utilizes a side weir structure to divert overflow water into treatment wetlands for storage and retention (Everest International Consultants, Inc. 2002). Treatment wetlands are also used to filter

pollutants from the water, thus improving water quality (Everest International Consultants, Inc. 2002).

The Tujunga Wash Greenway is a 1.6 mile restoration that recharges groundwater, provides habitat, improves water quality, and models a healthy ecosystems. The Headworks Groundwater Recharge Project (HGRP) ensures that a portion of LA River flow will be diverted to groundwater recharge. The summer reclaimed water flow is about 70%, with 40% reclaimed water input during winter (Everest International Consultants, Inc. 2002).

Near the end of the Los Angeles River in Long Beach, 50 acres of treatment wetlands were restored at the Dominguez Wetland Gap. The project is split into two sections, a 37-acre East Basin of treatment wetlands and a West Basin housing 15 acres of spreading grounds for groundwater recharge. The East Basin treats approximately 2-3 cfs (cubic feet per second) of water naturally, and remove large debris in the water via trash booms (Los Angeles County Department of Public Works 2006). The West Basin infiltrates up to 450 acre-feet of water into the groundwater aquifer per year (Los Angeles County Department of Public Works 2006). The Dominguez Wetland Gap restored the following ecosystem services: habitat, water quality, provisioning clean water, pollution and toxicity control, and flood abatement.

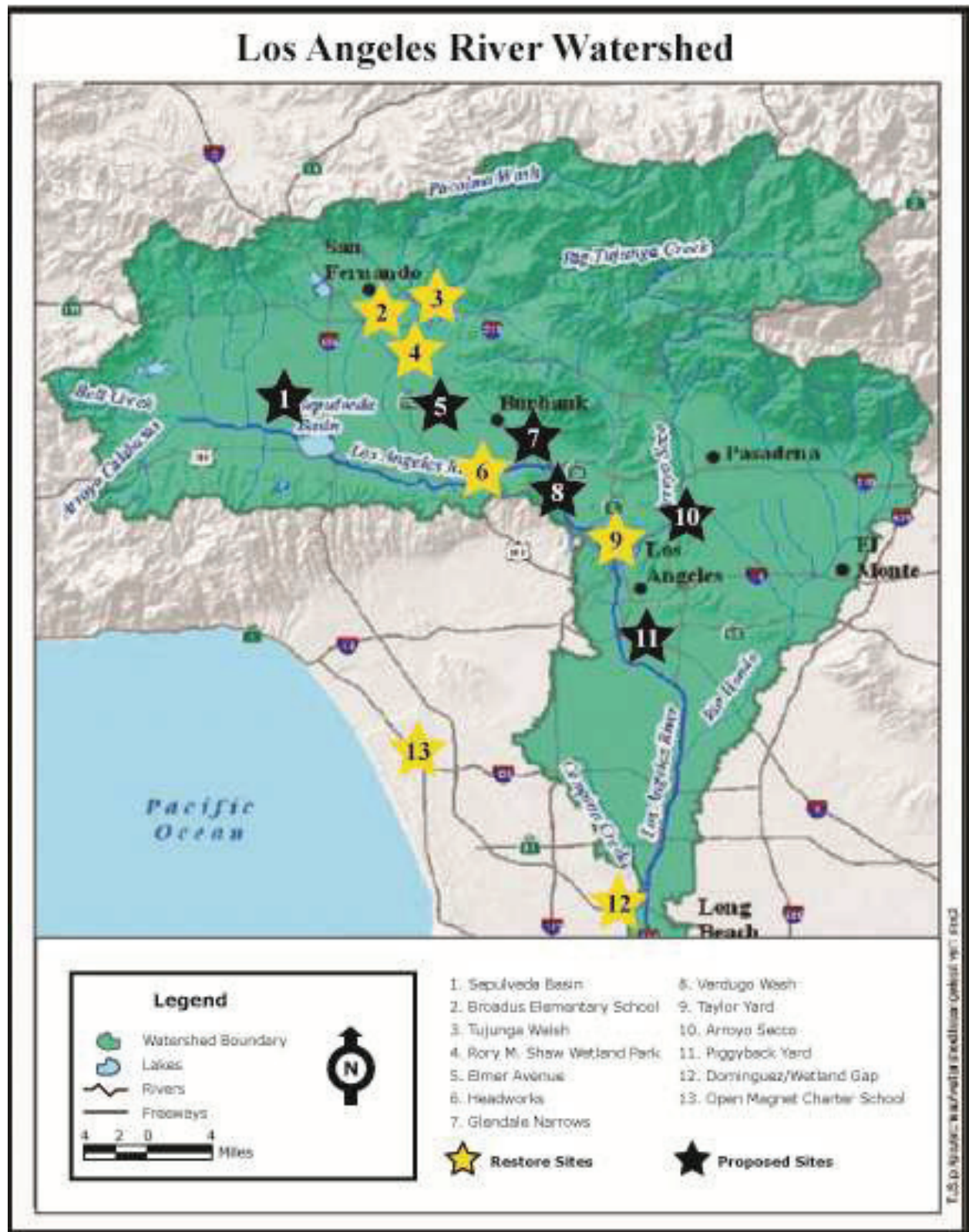


Figure 3. Map of the Los Angeles River watershed with current (yellow stars) & proposed (black stars) restoration projects (Photo source: Pacoima Wash Project & Angela Yi).

Various off-site restoration projects have been conducted by TreePeople in the Los Angeles watershed. The treatments used increased infiltration with dry wells while concurrently increasing stormwater retention and decreasing runoff by utilizing cisterns and swales. The scale of these projects ranged from a residential unit in South Los Angeles (Hall House) to a larger educational restoration projects at two middle schools: Hillery T. Broadous Elementary School project in Pacoima (a neighboring watershed) and Open Charter Magnet Elementary (TreePeople 2007). These projects act as small-scale watersheds and demonstrate the abilities of small-scale watersheds to reduce runoff, increase infiltration and decrease quantities of greenwaste within a large-scale watershed (TreePeople 2007). The ideology hypothesizes that as each small-scale watershed is restored (each site), the overall large-scale water catchment flow-regime will be restored downstream.

The Elmer Avenue neighborhood retrofit managed water resources with the retrofit of a flood-prone, residential neighborhood of Sun Valley in the northeast San Fernando Valley. The project's goal was to capture, treat, infiltrate and reduce the runoff of the surrounding 40 acres (Belden et al. 2012). The design utilized an underground infiltration gallery, bioswales on public right-of-ways, permeable walkways and driveways, rain gardens and rain barrels, and planted drought tolerant landscaping (Belden et al. 2012). The design of the project incorporated monitoring devices to provide water quality data to determine the successfulness of restoration (Alduenda 2014). The preliminary data suggests the catch basin improved water quality by removing a majority of the metals and total suspended solids before infiltration (Belden et al. 2012). After the first year of implementation (2010-2011), the Elmer Ave project successfully captured 10 acre-feet of runoff, filtered it in the infiltration gallery, and infiltrated it into the groundwater (Belden et al. 2012). In addition to the street retrofit, 13 residential homes were retrofitted with LID treatments (Belden et al. 2012). The off-site project enhanced ecosystem services by restoring water quality, habitat, and increasing water storage capacity (Belden et al. 2012). Overall, residents felt that maintenance to the retrofit was simple and quick (Belden et al. 2012). This project has been well received that and will be continued along to Elmer Paseo, a 270-foot pedestrian walkway (Belden et al. 2012). Elmer Avenue exemplifies the success of utilizing natural hydrologic process of infiltration for storm management in a cost-effective, successful, sustainable approach

4.7 Restoration Proposed on the LA River

Currently, there is an eleven and a half mile stretch of the Los Angeles River that is feasible to restore because of its accessibility to open space and its earthen river bottom. The eight-part proposed restoration is associated with the Los Angeles River Master Plan (LARMP). The LARMP was created to summarize the constraints and opportunities of the LA River restoration; focusing on flood management, recreation, aesthetics, economics, and environmental enhancements. A feasibility report was conducted by the USACE on these sites and recommended several different alternatives for restoration ranging from large-scale restoration techniques, to low impact habitat restoration or ‘band-aid’ type approaches. Examples of large-scale restoration include the demolition and excavation of a 31-foot long stretch of the channel bottom at reach seven on seen on Figure 4 (Los Angeles District 2013). Low impact approaches focus on restoring vegetation and habitat, without considering storm flow or runoff infiltration. Furthermore, a planter box treatment will be placed on the edges of the retaining walls 50 feet into the stream channel. In addition, the bottom six feet of the channel will be filled with riprap and the top six feet filled with sediment and secured with concrete baffles to reduce scouring (Los Angeles District 2013). There are a variety of sustainable alternatives proposed, however the low impact habitat restoration is not feasible because it does not address the crucial urban river flow-regimes.

The Rory M. Shaw Wetland Park Project was recently adopted in October of 2013 as an off-site flood protection project. It is located in Sun Valley which floods frequently because there is no formal flood protection infrastructure. The project is a 46-acre multipurpose wetland park with a 4.75-mile long storm-drain system that leads to a retention pond (Los Angeles County Department of Public Works 2013b). Once finished, the water will move from the retention pond to the habitat wetlands where it will be filtered, then pumped into Sun Valley Park for groundwater recharge (Los Angeles County Department of Public Works 2013b). The park will utilize recycled water for landscaping purposes. This park will restore and enhance ecosystem services such as: water quality, habitat, flood protection, hydrologic regime, and recreation. This off-site project will increase the sustainability of the watershed and improve the water quality downstream.

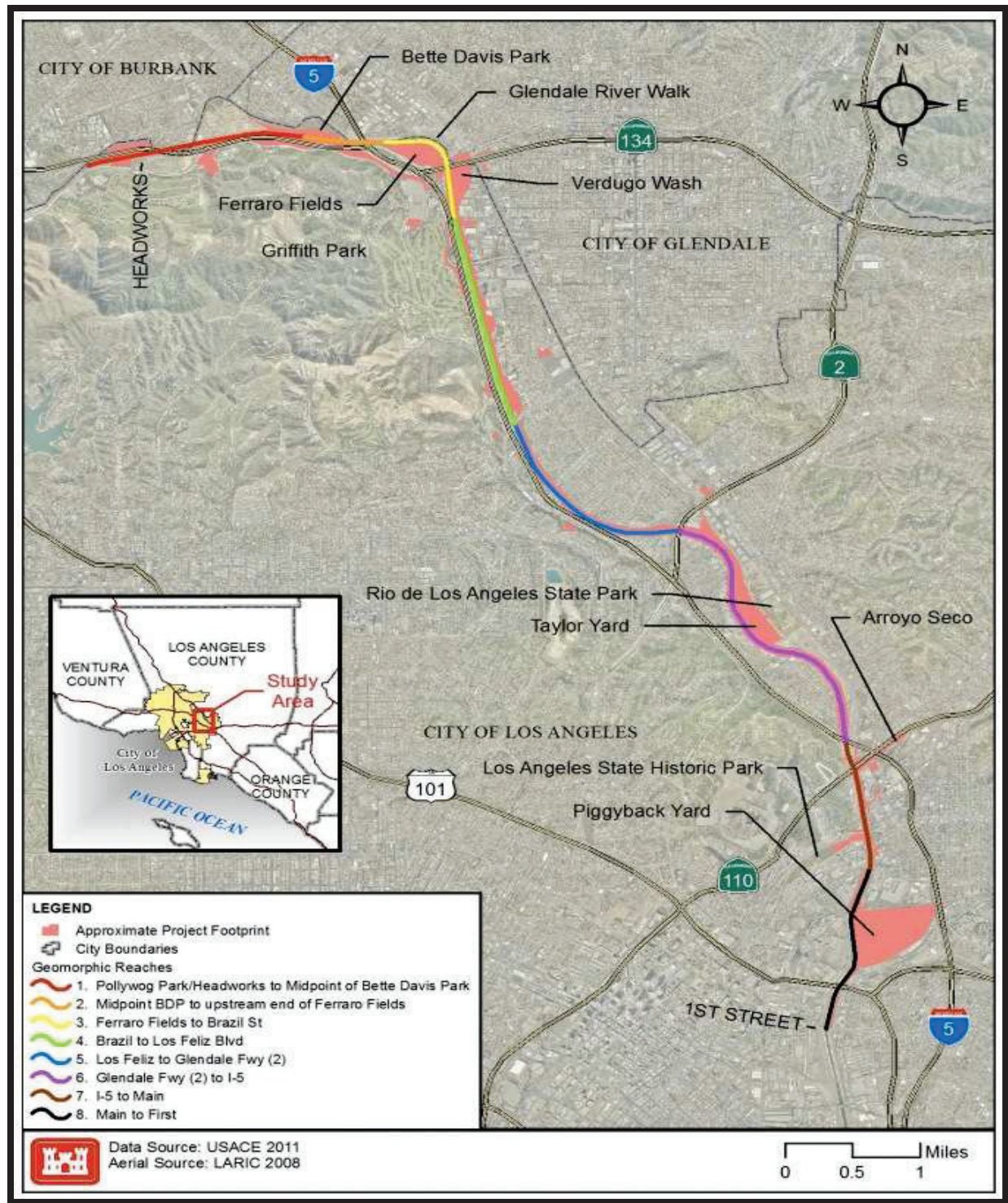


Figure 4. Map of possible treatment sites on the Los Angeles River from the USACE, highlighting each different restoration reach and the pink highlight depicting the project's footprint. (<http://www.infrastructureusa.org/wp-content/uploads/2013/09/Figure-ES-3.jpg>)

5.0 Discussion of Restoration Treatments and Solutions for the LA River

As discussed previously, there are major constraints that influence the accessibility of successful restoration along the Los Angeles River. Past feasibility monitoring reports, conducted by the USACE, examined several specific areas where restoration is possible along the LA River. These reports also highlighted areas which are unable to successfully restore provisioning or regulating ecosystem services.

Restoration feasibility is based upon the likelihood of restoring ecosystem services by implementing different on-site and off-site treatments. The five ecosystem services evaluated for each treatment are: water quality, hydrologic regime, pollution control, flood protection, and erosion control. Furthermore, it is noted when treatments enhance habitat but no further analysis was conducted. On-site treatments evaluated include: treatment wetlands, habitat wetlands, levee setback/removal, groundwater recharge, bypass channels, bioengineering streambank erosion, weir/rock vane/barb, fascines/bundles/wattles, revegetation with geotextile mats, invasive species removal, and retention ponds. Off-site treatments evaluated include: underground catchment basins, drywell and grading, retention grading, vegetated and mulched swales, cistern or rain barrel with roof catchment, bioretention, and porous pavement. Table 4 and Table 5, below, summarize each treatment based on cost, additional maintenance concerns, and ecosystem services restored for on-site treatments and off-site treatments, respectively.

5.1 Feasibility for Los Angeles River Restoration

Park, Pincetl and Stenstrom (2008) conducted a study on the LA River's water quality that evaluated compliance of TMDLs. Overall, the proposed in-stream channel restoration projects proposed would not sufficiently reduce the amount of contamination to be in compliance with the TMDLs; there needs to be additional restoration to be in compliance (Park, Pincetl and Stenstrom 2008). Enhancing the natural flow-regime of the river in-stream is not sufficient to restore the water quality of the LA River. A connected, dynamic on- and off-site treatment approach will need to be implemented in order to fulfill the TMDLs for water quality.

Past conventional stormwater treatments fail to address the flow-regime of the urbanized drainage system in place. (Burns et al. 2012). Newer approaches, such as LID treatments, combat this failure by utilizing constructed wetlands, vegetated swales and biofiltration to focus on load-reduction and mitigation of peak flows. While LID treatments effectively decrease the amount of

water in the river flow, monitoring data have not found it to be successful in restoring stream health (Burns et al. 2012). In response to this, Burns et al. (2012) recommends the use of small-scale treatments that aim to restore or create ‘natural hydrologic processes’ and use large-scale projects to focus on ‘restoring natural flow-regimes’ downstream. Natural flow-regime is defined as “the ecological integrity of river ecosystems depend[ing] on their natural dynamic character” (Poff et al. 1997) combined with data regarding the river’s natural, pre-urbanization flow. (Hamel, Daly and Fletcher 2013). When applied to the surrounding watershed, these dynamic approaches increase the feasibility of restoration success along the LA River.

There are minimal baseflow and low flow considerations in LID implementation due to the complexity of inputs to subsurface flow in urban watersheds (Hamel, Daly and Fletcher 2013). Baseflow is categorized as flow originating from groundwater or ‘delayed sources’ and low flow describes a decreased flow rate after “prolonged dry weather” (Hamel, Daly and Fletcher 2013). The current LID approach decreases stormwater loads, but does not restore the baseflow of a river. Baseflow is important for habitat maintenance by enabling the transport of nutrients and sediment within the waterway. To restore the baseflow and low flow, off-site treatments concentrate “source-control infiltration” to enhance the watershed’s natural flow-regime.

A baseflow study performed by the HYDRUS_2D, a modeling tool that analyzes water flow and transport, tested the infiltration of a 33% urban cover landscape. Roof runoff was diverted to infiltrate trenches and swales, instead of entering the storm drain. This increased the natural hydrologic processes which resulted in a 40% increase in baseflow (Hamel, Daly and Fletcher 2013). Infiltration of precipitation into the groundwater positively increased the sustainability of watershed health. Although increased infiltration enhances watershed health, certain considerations should be made for Mediterranean-type rivers because of severely low baseflow. For example, design constraints of low flow under drains fail to increase low flow infiltration in this circumstance and should not be used. (Hamel, Daly and Fletcher 2013). Conventional load-reduction solutions decrease flood risk, however alternative storm management techniques apply treatments that increase baseflow and infiltration as well. This has been shown to have higher success at sustainably restoring flood protection within a watershed.

5.2 Treatments

The following restoration treatments are categorized based upon the location of each treatment in relation to the river flow. Each of the 18 treatments below is summarized, evaluated in terms of cost-effectiveness, and are assessed based on ecosystem services restoration. Cost is evaluated on a low (\$100-\$1,000), medium (\$1,000 - \$10,000), and high (\$10,000+) scale. In terms of scale, this study's analysis focused on the size that a majority of the treatments are implemented. Additionally, it is noted when treatments can be applied on a variety of sizes or scales, depending on the needs of the restoration.

5.2.1 On-Site Treatments

On-site treatments directly affect the processes of river flow. They are either located within the streambank or are located near the stream channel and directly interact with the river flow.

Treatment Wetlands

Treatment wetlands use natural filtration to improve water quality by passing sub-surface water flow through microbes, vegetation, and soil (Figure 5) (Everest International Consultants, Inc. 2002, Gosselink and Mitsch 2007). Degrees of water quality enhancement differ depending on each site, but past tests on small and large-scale sites (E.g. the Mississippi and the Everglades) confirm positive water quality improvements (Gosselink and Mitsch 2007). The created wetlands are normally located off the main stream to avoid contamination or flooding to the wetland (Everest International Consultants, Inc. 2002) and only use one or two different types of hydrophytic, water-loving, plants. Furthermore, considerations of harvesting and re-plantation of hydrophytic species is needed to maintain the appropriate level of filtration. Acquiring the necessary land area to successfully filter the water may be difficult in urban areas. Additionally, while the cost to install a treatment wetland is high, it is still less costly to create a treatment wetland (even with yearly maintenance) than to create a waste treatment plant to improve water quality (Gosselink and Mitsch 2007).

Habitat Wetland

Habitat wetland creation focuses on the ecosystem functionality and the creation of natural riparian habitat, as seen in Figure 5 (Gosselink and Mitsch 2007), whereas treatment wetlands use specific hydrophytic plants for filtration and improving water quality. A densely

vegetated area has a high affinity to uptake nutrients and metals in the water column, and has a strong ability to retain sediment which improves water quality. Habitat wetlands require surface flow to mimic the year-round hydrologic regime of natural wetlands (Gosselink and Mitsch 2007). Unfortunately this approach requires substantial acreage to appropriately restore the natural surface flow. Habitat wetlands require strategic and labor intensive installation. Additionally, yearly maintenance of vegetation and invasive species removal is needed to retain the integrity and successfulness of the ecosystem. The cost of treatment varies between low and high (\$100- \$10,000+) depending on the complexity and acreage being restored. Nonetheless, the benefits from providing a natural habitat are indispensable in urbanized areas (Everest International Consultants, Inc. 2002). Habitat wetlands provide additional benefits including natural habitat and recreation opportunities for the surrounding community.



Figure 5. Examples of the differences of vegetation between treatment wetlands (left) and habitat wetlands at Thompson Reach (right) (<http://www.ccwa.us/news/Huie-Constructed-Treatment-Wetlands-Phase-4-Now-in-Operation> and Presidio Trust San Francisco).

Levee Setback/ Relocation

Levee relocation demolishes existing flood-control levees and sets them further away from the flood channel to provide a larger area for wetland and floodplain habitat to flourish (Everest International Consultants, Inc. 2002). Surrounding developed land use constrains the success of this treatment. It is most successful when applied in areas that have the appropriate acreage available. The increased habitat area and vegetation increases filtration and improves water quality. Additionally, the increased floodplain reduces river flow velocities by providing

room for the river to spread, decreasing flooding and increasing infiltration (Everest International Consultants, Inc. 2002). Seasonal recreation can also be housed within the floodplain of a river during low flow months. Despite these benefits, levees are not a sustainable treatment for flood protection and must be monitored and maintained regularly to perform properly. Additionally, this treatment is costly because of the intensive physical labor needed to remove concrete and move levees.

Groundwater Recharge

For drinking water purposes, it is important for Mediterranean-type rivers to divert portions of stormwater and runoff into groundwater aquifers. About half of California's drinking water is derived from groundwater (Mount 1995). During droughts a heightened amount of water is drawn from the aquifers, increasing hazards of water quality degradation and increasing potential for bacteria to occur (Mount 1995). Diverting stormwater and runoff into groundwater increases the extraction capacity of groundwater. However, precautions are needed when increasing groundwater recharge in an urban environment. Runoff and stormwater can be contaminated with oil or other pollutants that could contaminate and decrease water quality. The costs associated with large-scale groundwater recharge are dependent upon the capacity and in-place infrastructure of the aquifer. The application of this treatment involves concrete removal in the streambed which is very costly and labor intensive. Furthermore, constant monitoring of groundwater quality is needed to ensure TMDLs and safe drinking water levels are being met.

Bypass Channels

Bypass channels are used in urbanized areas as a mechanism to prevent flooding. During high flood events, river flows are diverted into a network of underground culverts to prevent overflow flooding (Santa Clara Valley Water District 2014). Additionally, the channels protect in-stream vegetated habitat from being destroyed by rapid and intense flows. Unfortunately, bypass channels are unsustainable because they only treat the symptoms, not the causes, of flooding. Implementation is constrained by the current physical infrastructure, as it is costly to excavate in an urbanized setting. Furthermore, depending on the capacity needed to divert storm flow, the costs of physical labor and the large amount of culvert and pipe material can be expensive.

Bioengineering Streambank Erosion

Bioengineering combines living and non-living vegetation construction treatments to stabilize and control erosion within a streambed (Allen and Leech 1997). Preliminary bed stability is a constraint for the upper and lower reaches of the restoration project. 'Hard toe and flanking protection' and deflection structures should be utilized to ensure stabilization prior to implementing bioengineering techniques (Allen and Leech 1997). Examples of treatments include: coconut mats, toe protection, weirs, barbs, vanes, bank crib with cover, coir geotextile rugs, and vegetation geogrid. The benefit of using these techniques is tri-fold, it 1.) improves stabilization by decreasing erosion and increasing sediment accumulation 2.) provides a natural habitat for wildlife (Bernhardt and Palmer 2007) and 3.) aids in the protection of the capacity of the stream channel (Arizona Department of Environmental Quality). Despite these benefits, this approach is not self-sustaining. However, these treatments can be successful when applied in conjunction with other treatments. Furthermore, the causes of sedimentation and erosion are not addressed with bioengineering techniques (Trimble and Ward 2003). In terms of installation, the cost varies from low to high (\$100-\$10,000+) depending on the assortment of treatments and the acreage restored. Maintenance and replacement of these treatments are required, especially after large flood events which can dislodge or damage the effectiveness.

Fascines/Bundles/Wattles

Fascines, bundles or wattles utilize dormant branches that are bound together to create a log structure on the streambank to slow stream flow and prevent erosion, as well as promote habitat (Figure 6). Similarly, willows and softwoods can be placed perpendicular to the stream so that they can take root and grow to shade the stream (Arizona Department of Environmental Quality: Water Division). Fascines, bundles and wattles naturally slow down the velocity near the streambanks and promote soil accumulation while reducing erosion. Additionally, they create an area for plants to propagate naturally (Arizona Department of Environmental Quality: Water Division). The cost of implementation is low (\$100-\$1,000), with labor being the highest cost.

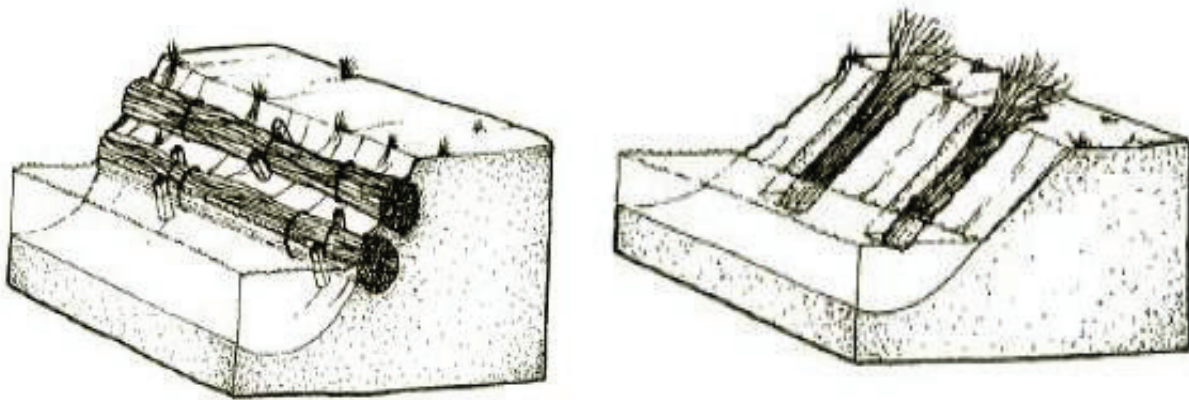


Figure 6. Examples of the placement of a facine, bundle, or wattle along a streambank. These treatments are made from living and non-living vegetation (Arizona Department of Environmental Quality: Water Division).

Weir/ Rock Vane/ Barb

Weirs, rock vanes, and barbs are used to decrease velocity of streams and reduce streambank erosion. The purpose of the weir is to concentrate the stream flow into the center of the river so that flow near the banks is slower to decrease erosion (Arizona Department of Environmental Quality: Water Division). Rocks, logs or large sturdy debris are strategically placed within the stream to guide the flow of the channel, as seen in Figure 7. Weirs also promote pools, gravel bars, and riffles which are conducive to in-stream wildlife habitat (Arizona Department of Environmental Quality: Water Division). This treatment is a natural solution to slow stream velocity to promote a more natural flow regime. The cost of implementation is relatively low (\$100-1,000), depending on the number and size of the treatment. However, scheduled maintenance should monitor the functionality of the treatment, especially after significant storm events.



Figure 7. Example of a rock vane restoration in a stream channel, notice the higher velocity flow concentrated in the middle of the stream to decrease streambank erosion (Arizona Department of Environmental Quality: Water Division)

Revegetation with Geotextile Mats

Streambanks can be revegetated and protected with the addition of geotextile mats. The mat protects the newly planted species while stabilizing the bank (Bernhardt and Palmer 2007). Revegetation enhances streambank stabilization as well as improves the aquatic habitat and increases species biodiversity (Bernhardt and Palmer 2007). Revegetation can decrease soil and groundwater contamination through phytoremediation, (utilizing plants to increase water quality) and uptake contaminants such as heavy metals, PCBs, radionuclides, chlorinated solvents, petroleum hydrocarbons, and pesticides (Khan, Husain and Hejazi 2004). This treatment employs minimum disturbance to the river channel and benefits habitat and water quality. Additionally, this treatment is less expensive than excavating contaminated soil. Appropriate planning of plant placement along the streambank will ensure that the water level and stormwater flow will sustain the vegetation. Geotextile mats can have a high cost (\$10,000+) because of the large quantity and dimensions of the material. Regular replacement and monitoring is required, especially after large storm events which can uproot the material.

Invasive Species Removal

Invasive species disrupt the natural flow-regime and the amount of available nutrients in the ecosystem (Arizona Department of Environmental Quality: Water Division). Invasive species out-compete native plants for vital resources, habitat, and disrupt the natural food distribution. Detection and removal of invasive species are important to prevent flooding and control erosion in riverine systems (Arizona Department of Environmental Quality: Water Division). There are chemical, biological, or physical techniques that can be used for removing invasive species. Depending on the acreage, life form, and level of invasion, this treatment's cost ranges from low to medium (\$100-\$10,000). Removal can be labor intensive and requires diligent monitoring, combined with adaptive management to ensure successful eradication.

Retention Ponds

Retention ponds or lakes provide temporary on-site water storage and act as a settling and debris basin (Figure 8). The ponds only divert stormwater runoff, not normal flow. This treatment increases lag time and decreases the intensity of the peak discharge (Mount 1995). Retention ponds replicate a river's floodplain by providing storage and geomorphic depressions for water (Mount 1995). Additionally, it will provide seasonal wildlife habitat. Surrounding developed land use restricts the application of retention ponds. Possible vector issues can also occur within retention ponds, depending on the location of the treatment. The high costs associated with retention ponds are due to the cost of land acquisition and soil excavation and removal. Maintenance is required for debris removal, vector control, and dredging of sediment accumulation.



Figure 8. Retention pond with culvert, notice the absence of vegetation.
<http://dunwoodyusa.blogspot.com/2010/08/dunwoody-high-retention-pond-street.html>

5.2.1.1 On-Site Treatment Feasibility

Large-scale, on-site restoration treatments are needed to successfully restore the in-stream hydrologic regime of rivers. The county of Los Angeles now requires LID implementation for all new development. The economic feasibility of these solutions will increase as development and implementation of these treatments are main-streamed (LACDPW 2013a). On-site treatments are able to improve a large quantity of river flow processes. However, these treatments have additional obstacles and conflicts due to a large number of stakeholders, residents, and development (Cooper et al. 2013) - which is a barrier to restoration success. These on-site restoration treatments are necessary because current restorations are ineffective; they are conducted at scales too small that are disconnected (Cooper et al. 2013, Wohl et al. 2005). The largest limitation of these in-stream treatments is the lack of fluvial geomorphic restoration (Tompkins and Kondolf 2007) due to developed land use restrictions. Consideration of the low-flow elevation and the connectivity to the floodplain and vegetation should be assessed while planning and monitoring to ensure restoration success (Tompkins and Kondolf 2007).

5.2.1.2 Ecosystem Services and Cost Analysis

All of the five ecosystem services are restored from on-site treatments; however the majority of treatments restored water quality, hydrologic regime, and flood protection (Table 4). Bypass channels and retention ponds are not cost-effective. They both only restore flood

protection and both have high costs for implementation (Table 4). Additionally, treatment wetlands only contributed to two ecosystem services: water quality and pollution control and have high costs as well. Habitat wetlands and invasive species removal restored over four of the ecosystem service objectives and had variable costs (Table 4). Restoration should focus on cost-effective treatments that provide multiple benefits, like habitat wetlands and invasive species removal.

Table 4. Costs and ecosystem services provided by each on-site treatments (Khan, Husain and Hejazi 2004, Arizona Department of Environmental Quality: Water Division)

Treatment Name	Cost	Maintenance Requirements	Direct Ecosystem Service Restored
Treatment Wetland	High	Harvesting and replanting of vegetation and soil (question of disposal)	-Water quality -Pollution control
Habitat Wetland*	Low-high	Replanting and trimming	-Water quality -Hydrological regimes -Pollution control -Flood protection
Levee Setback/ Relocation*	High	Levee maintenance	-Hydrological regimes -Flood protection
Groundwater Recharge	High	Monitor connectivity	-Water quality -Hydrological regimes -Flood protection
Bypass Channel	High	Monitor for leaks or debris	-Flood protection
Bioengineering Streambank Erosion	Low-high	Replacement or repair	-Water quality -Hydrological regimes -Flood protection
Weir/ Rock Vane/ Barb*	Low	Replacement or repair	-Water quality (re-oxygenate) -Erosion control
Fascines/ Bundles/ Wattles*	Low	Replacement or repair	-Water quality -Erosion control
Revegetation with Geotextile Mats*	High	Replacement or repair	-Flood protection -Erosion control
Invasive Species Removal*	Low-medium. Cost dependent on growth form or invasion level of species.	Monitoring for repeat removal or different techniques	-Water quality -Flood control -Hydrological regime
Retention Ponds	High	Debris removal and vector control	-Flood protection

Legend: Low = \$100-1,000 Medium = \$1,000-10,000 High= \$10,000+

*= habitat creation

5.2.1.3 Community Involvement

There are not many direct opportunities available for community involvement for on-site treatments. Volunteers can install vegetation and maintain plant survival for habitat wetlands, levee setback/ relocation, and bioengineering structures. Additionally, treatments such as groundwater recharge, habitat wetlands, and treatment wetlands can be showcased for educational purposes. Habitat wetlands and retention ponds are able to incorporate recreation within the treatment design. Overall these treatments require expertise and labor intensive work that cannot be provided by an average resident. On-site treatments directly enhance a large volume of surface water quality and improve the natural flow regime; however, they do not engage or solicit the opportunity of the surrounding community.

5.2.2 Off-Site Treatments

Off-site treatments indirectly affect the processes of river flow by enhancing the natural hydrologic process within the watershed. They are located within the river's watershed, away from the river and not directly connected to river flow.

Underground Catchment Basins

The underground catchment basin treatment utilizes the dynamic process of retention ponds in conjunction with groundwater infiltration. Water is collected in a catchment basin and is stored and treated in an 'infiltration gallery'. Once the water is filtered, it is expelled to percolate into the soil and groundwater (TreePeople 2007). The treatment's design is a concrete box with steel baffles inside that hydraulically separate out the sediment, oil, and other pollutants (TreePeople 2007). This solution is similar to a treatment wetland but requires less maintenance and takes up less space. It is best used in urbanized areas because it can be placed under fields and parking lots. The installation cost varies on the size of infiltration gallery and the type of infiltration used. Considerations of location and maintenance of the infiltration gallery are crucial during planning. A combination of 220 units holds roughly 95,200 gallons of water with a total construction cost of \$217,996 (TreePeople 2007).

Drywell and Grading

A drywell system increases water quality and infiltrates stormwater runoff into the soil. A drain catches the runoff and directs it into an area filled with sand and crushed rocks that collects pollutants and oil before it percolates into the soil groundwater (TreePeople 2007). This can be

used on small-scale sites, as seen in Figure 9, and on large-scale projects. Maintenance to clear the grate of debris and replacement of the sand and rocks may be necessary to ensure proper pollutant filtration (TreePeople 2007). The initial cost can range from \$ 1,400 to \$1,900, including additional labor costs (TreePeople 2007).

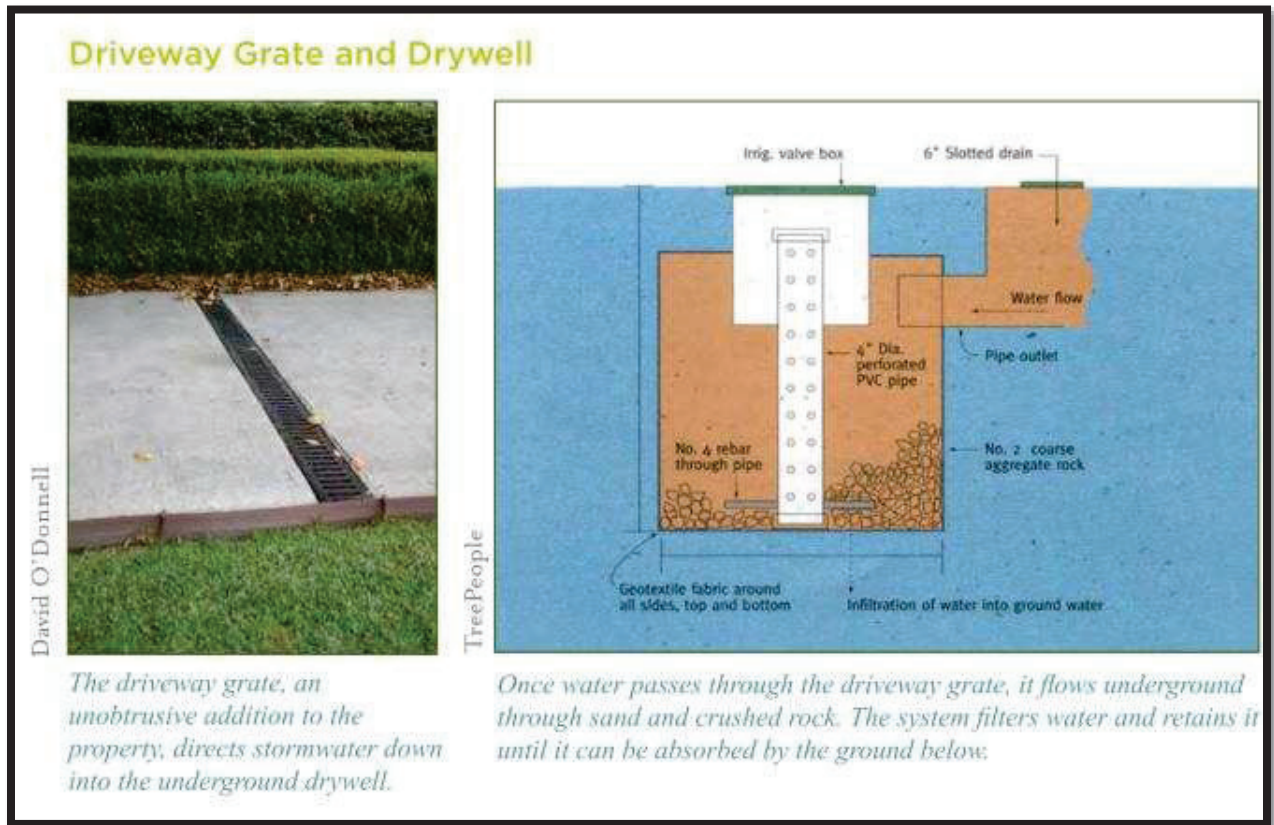


Figure 9. Driveway grate and drywell example and diagram explaining the infiltration and filtration of water (TreePeople 2007).

Retention Grading

Retention structures are created to hold the stormwater and runoff that fall for 72 hours before it is filtered and percolates into the soil (TreePeople 2007). When maintained properly, small-scale structures are able to handle a 100-year flash flood event, an equivalent to 5,800 gallons of water (TreePeople 2007). The initial cost involves earth moving, land cost, and installation of the overflow mechanism. Sediment accumulation or loss should be monitored after storm events to ensure appropriate height levels are maintained (TreePeople 2007). The initial cost can range from \$ 800 to \$1,600, including additional labor cost (TreePeople 2007).

Vegetated and Mulched Swales

Swales are open-channel drainage systems that replace the use of storm sewer pipes and increase infiltration, as seen in Figure 10. There are several different types of swales; however the vegetated and mulched swale combines greenwaste and retention depressions which filter the water and increase infiltration of groundwater (TreePeople 2007). Residential swales utilize on-site greenwaste or grass to cover the swales. Furthermore, scale can be adjusted to the site. This treatment is most often used for residential solutions to decrease stormwater runoff and increase watershed sustainability, but can also be used commercially. Maintenance of the onsite greenwaste involves creating compost and mulch (TreePeople 2007). The initial cost can range from \$ 30 (for seed) to \$ 1,000, including additional labor cost (TreePeople 2007).

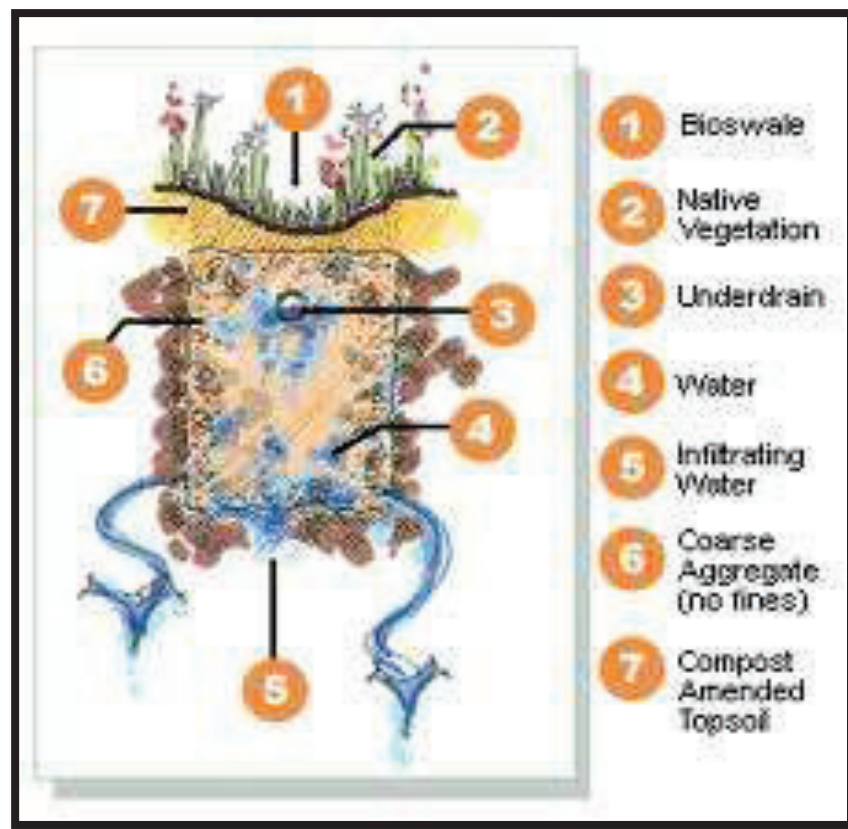


Figure 10. A representation of the components and processes of bioswale infiltration.

(http://www.cityofchicago.org/city/en/depts/water/supp_info/conservation/green_design/drainage_swales.html).

Cistern or Rain Barrel with Roof Catchment

A cistern or rain barrel is a basic tank that retains water for later (non-potable) use. Combined with a 'first flush diversion unit' the system collects roof runoff, settles out the pollutants and debris, and then holds it for later irrigation use (TreePeople 2007). These systems can be used at a large-scale commercial scale or smaller residential scale. Hall House, a demonstration project by TreePeople in Downtown Los Angeles, utilized a larger scale two 1,800 gallon cisterns (Figure 11) (TreePeople 2007). Smaller scale treatments can be applied by using rain barrels, which hold as little as 55 gallons (Figure 12). Treatment and cleaning of the water in the cistern or rain barrel may be required to kill any vector or bacteria problems. Release of the 'first-flush unit' is required to ensure proper room per storm event and to decrease contaminants from the roof (TreePeople 2007). The Hall House example is a high-end custom-made UV-proof and earthquake safe recycled plastic cistern for \$25,000 with four roof runoff extensions from \$120 to \$380 including labor and additional costs (TreePeople 2007). Smaller, 55 gallon rain barrels range from \$80-\$120, but can be less expensive with do-it-yourself kits (Low Impact Development Center Inc. 2010). This treatment provides a long-term investment when used and maintained properly, it can have a lifespan of 50 years (Low Impact Development Center Inc. 2010).

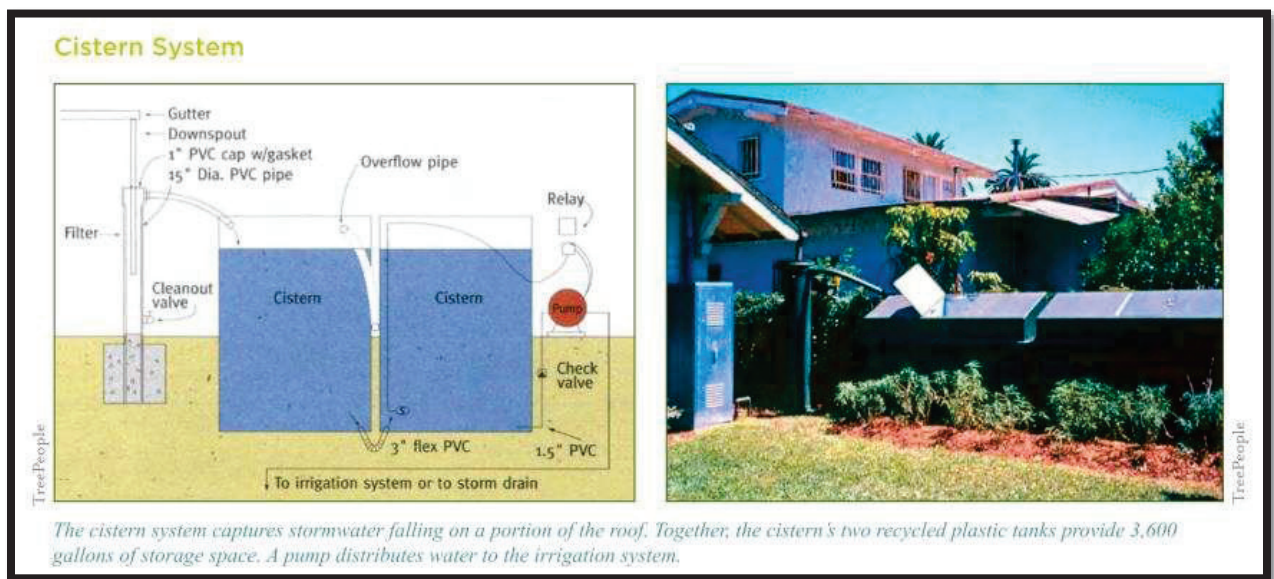


Figure 11. A cistern system example and diagram explaining the water gathering and retention process in a residential application (TreePeople 2007).



Figure 12. Residential rain barrel in Los Angeles with hose attached for on-site use (Low Impact Development Inc. 2010)

Porous Pavement

Porous pavements replace traditional impervious surfaces with material that allow precipitation and runoff to infiltrate into the soil. Once in place, regular maintenance is required to ensure that water is able to infiltrate into the soil. This treatment should not be used if there is a significant slope or in high traffic areas that are prone to oil or contaminate spills, such as industrial areas or highways (Low Impact Development Center Inc. 2010). As seen in



Figure 13, there are many different types (pavers, concrete, asphalt, etc.), sizes, and uses for this treatment. Examples include walkways, playgrounds, parking lots, tennis courts, plazas, and

sidewalks (Low Impact Development Center Inc. 2010). Figure 14 gives a step by step explanation of how porous pavement increases infiltration, filters stormwater, and reduces runoff (Low Impact Development Center Inc. 2010). Cost is slightly higher than traditional paving material but depends on the type of material used and the amount needed (Low Impact Development Center Inc. 2010).



Figure 13. Examples of porous pavements. Turfstone pavers pavement (left), cross section of how porous asphalt utilizes rock material for infiltration (middle) and commercial implementation of pervious pavers for parking stalls in Redlands, California(Low Impact Development Inc. 2010).

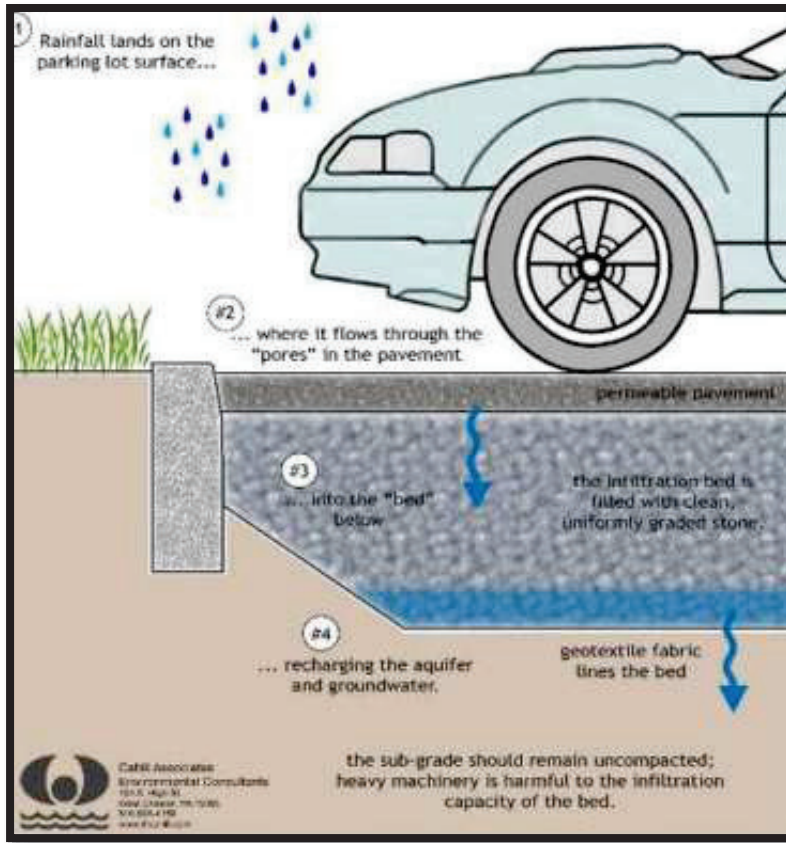


Figure 14. Step-by-step explanation of water infiltration by porous pavements (Low Impact Development 2010).

Bioretention

Bioretention diverts stormwater runoff into a small shallow, vegetated depression to be filtered and absorbed into the soil (Figure 15). These depressions can be incorporated into residential or commercial landscapes. This treatment improves water quality, decreases pollutants, reduces stormwater, and provides habitat (Low Impact Development Center Inc. 2010). Permeable soils, access to groundwater, and possible irrigation are the constraints of bioretention (Low Impact Development Center Inc. 2010). Debris removal and plant maintenance is required. Cost is generally less than traditional landscaping and includes excavation, planting, and diversion of the current stormwater system.



Figure 15. Examples of bioretention cells. Residential rain garden (left) with roof drainage diversion. Commercial treatment of bioretention (right) in a parking lot in San Diego (Low Impact Development Center Inc. 2010).

5.2.2.1 Off-Site Treatment Feasibility

The non-profit organization, TreePeople, implemented and tested the off-site projects' successfulness within the Los Angeles Watershed. Hall House tested the retention of 4,000 gallons of water from 'rain' of a fire hose (TreePeople 2007), all of which was retained on the property. The Broadus School Project retained 99.9% of the water that fell within it over a year, equaling approximately 126,000 cubic feet of water annually (TreePeople 2007). After these sites were initially tested, no monitoring has continued and the Hall House site has been decommissioned (de Guzman 2014). Collaboration and maintenance of the treatments have proven to be difficult without full direct interest or support from these institutions. The benefits of these off-site projects have improved the water 'self-sufficiency' of neighborhoods and communities (The River Project 2013). Not only are these treatments highly productive, they are also moderately cost effective and practical (The River Project 2013). The off-site projects have proven to realistically capture and retain a majority of the water within its reaches, however it is yet to be determined if this improves ecosystem services because of the lack of long-term monitoring data.

5.2.2.2 Off-site Ecosystem Services and Cost Analysis

The off-site restoration treatments provide a similar percentage of ecosystem services as on-site treatments; however, they provide less erosion control. Almost all of the treatments provide water quality restoration, except for the cistern/ rain barrel with roof catchment treatment because it only stores the water for non-potable re-use, it does not treat the water. The cistern is also the only treatment that provides one ecosystem service. The most cost effective off-site treatments are bioretention/ rain gardens and drywell and grading ([Table 5](#)). Pervious pavement may also be cost effective depending on the scale and type of material used. Although the underground catchment basin is costly, it provides the highest benefit of ecosystem services and treats the largest volume of water out of the other treatments.

Table 5. Costs, maintenance, and direct ecosystem services restored by each off-site treatment (derived from TreePeople 2007)

Treatment Name	Costs	Maintenance	Direct Ecosystem Service Restored
Underground Catchment Basin	High	-Cleaning and periodic replacement of steel baffles	-Water quality -Hydrological regimes -Pollution control -Flood protection
Drywell and Grading	Medium	-Replacement of filtration material and periodic clearing of debris	-Water quality -Hydrological regimes -Pollution control -Flood protection
Retention Grading	Low- Medium	-Monitoring of sediment loss/accumulation after large storm events to maintain appropriate height	-Water quality -Flood protection
Vegetated and Mulched Swales	Low	-Constant onsite greenwaste creation and application -Minimal removal of trapped pollutants	-Water quality -Flood protection
Cistern or Rain Barrel with Roof Catchment	Low-High	-Cleaning of cistern and diligent release of ‘first-flush’ during storm events.	-Flood protection
Bioretention/Rain Garden*	Low-Medium	-Landscaping maintenance and possible manual irrigation.	-Water quality -Flood protection -Hydrologic regime
Porous Pavement	Low-High	-Frequent cleaning and debris removal to make sure there is proper infiltration.	-Water quality -Hydrologic regime -Pollutant removal -Flood protection

Legend: Low = \$100-1,000 Medium = \$1,000-10,000 High= \$10,000+, *= habitat creation

5.2.2.3 Community Involvement

Community support and implementation is essential for off-site restoration treatments to be successful in providing ecosystem services. All of these treatments can be adjusted to smaller residential scale projects or can be enlarged to encompass a larger, commercial scale. Off-site treatments increase the sustainability of the watershed by utilizing and conserving the precipitation and runoff from storm events instead of expelling it into storm drains and increasing flood risk. Vegetated and mulched swales require community implementation and involvement to maintain the infiltration capabilities sustain the surrounding vegetation. Without the community implementation of off-site treatments in the watershed, the natural hydrologic process of the watershed would not be restored which is integral for the success of the overall riverine ecosystem health.

5.3 Summary of On-Site and Off-Site Treatments

Analyzing the results from Table 6, a majority of the treatments restore water quality, and flood protection. Out of the eighteen treatments reviewed, flood protection (83%) and water quality (72%) had the highest percentage of ecosystem services restored. Approximately 50% of the treatments enhance hydrologic regime. Pollution control and erosion control are both restored only by 28% of the treatments. All off-site treatments reviewed provide flood protection, however none of them restore erosion control. Furthermore, if erosion control is a main objective, then on-site treatments must be used. Three off-site treatments provide pollution control, compared to only two on-site treatments. Furthermore, only one treatment (habitat wetlands) reviewed restored all of the five ecosystem service objectives, but it can be an expensive on-site treatment depending on size and complexity. Restoration is most successful when combinations of on-site treatments are implemented along with a combination of off-site treatments. This analysis is important for restoration project planning because it references the specific restoration treatments based on the restoration of ecosystem services

Table 6. Summary of restoration treatments based on predicted restoration of ecosystem services.

On-Site Treatments	Name of Treatment	Water Quality	Hydrologic Regime	Pollution Control	Flood Protection	Erosion Control
	Treatment wetlands	✓		✓		
	Habitat wetlands*	✓	✓	✓	✓	✓
	Levee setback/ removal*		✓		✓	
	Groundwater recharge	✓	✓		✓	
	Bypass channels				✓	
	Bioengineering streambank erosion	✓	✓		✓	✓
	Retention ponds				✓	
	Weir/rock vane/barb*	✓				✓
	Fascines/bundles/wattles*	✓				✓

Off-Site Treatments	Invasive species removal*	✓	✓	✓	✓
	Revegetation with Geotextile mats *		✓		✓
	Underground catchment basins	✓	✓	✓	
	Drywell and grading	✓	✓	✓	
	Retention grading	✓			✓
	Vegetated and mulched swales	✓			✓
	Cistern or rain barrel with roof catchment				✓
	Bioretention	✓	✓		✓
	Porous pavement	✓	✓	✓	✓

Legend:

✓ =restored ecosystem service *= habitat creation

6.0 Management Implications and Recommendations

6.1 Lessons from other urban restoration

It is important to acknowledge the success and failures of past projects in order to properly plan the success of new projects. According to Kondolf (1998), the best criteria to evaluate a river restoration project's success are the restored geomorphologic and ecological processes. The National Research Council evaluated river restoration projects in 1992 in the United States and found the main cause for restoration failure was due to the oversimplified “cookbook approach”. The “cookbook approach” duplicates a standardized treatment approach and applies it to streams and rivers solely based upon stream type classifications without fully understanding the specific climate, fluvial geomorphology, hydrology, or sediment supply of the river (Hilderbrand et al. 2005, Bernhardt and Palmer 2007); a one-size-fits-all ideology. Additionally, reference sites chosen based on close proximity or historical references are no longer applicable models for restoration because of drastic increases in urbanization.

Lessons learned that are applicable to the outcome of the Los Angeles River restoration includes treatment trains, implementing less bank stabilization treatments, and encouraging the collaboration of agencies. ‘Treatment trains’, the use of multiple connected treatments, improve water quality and decrease peak flows more effectively than traditional practices of moving stormwater off-site and downstream for treatment (Bernhardt and Palmer 2007). Connected off-site restoration treatments improve the natural hydrologic process of the watershed and improve water quality health downstream. Diverse, connected projects are more efficient and effective at providing water treatment than conventional stormwater management. Bank stabilization treatments have been found by Bernhardt and Palmer (2007) to be less effective in urban restoration because intense storm events wash away the treatments. Since the Los Angeles River has severe flood events, bank stabilization will not be efficient in erosion control. Additionally, restoration should be based on the broader objective of restoring the watershed health, not just the in-stream river health. Collaboration and coordination of separate agencies successfully restore the overall watershed health, not just river health (Christian-Smith and Merenlender 2010). Knowing and applying these lessons to restoration planning will increase the feasibility of the LA River restoration.

There is a question between the overall effectiveness and self-sustainability of on-site versus off-site restoration treatments. The USEPA budgeted \$300 billion for nonintegrated wastewater projects in US cities in the next 20 years (TreePeople 2007). Because these projects are nonintegrated, the success of these projects is moderate to low and will not provide a solution to the cause of poor water quality. Although on-site treatments restore a larger volume of water per project, restoring the overall watershed health of the river by integrating off-site treatments will lead to higher river water quality success (TreePeople 2007). The River Project (2013) describes off-site restoration treatments as ‘urban acupuncture’- poking holes through permeable layers to reconnect precipitation, soil and river. River water quality is directly linked to the health and sustainability of the overall watershed. Additionally, the River Project supports the use of increased off-channel recharge facilities as a spreading basin to improve recharge in an urbanization-constrained environment (The River Project 2013). Off-site restoration treatments are important in assisting with the natural hydrologic process, which in turn, improves the health of the river.

6.2 Monitoring and Adaptive Management

Monitoring each type of treatment implemented is essential to understand the degree of ecosystem service achievement. A nationwide study conducted on coarse-scale restoration data concluded that success was widely unknown due to the lack of post-project monitoring data (Christian-Smith and Merenlender 2010). Since this data is not being gathered currently, it is an opportunity to instate practical monitoring protocols. Monitoring reports are most useful when data is comprehensive and transparent (Mooney et al. 2005a). There are several different types of reporting tools available for projects that restore or enhance ecosystem services; examples include: Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), and post-construction stormwater assessments by The Center for Watershed Protection (Center for Watershed Protection 2008, Everard and Moggridge 2012).

Currently, biophysical responses are used in monitoring to measure the success of a restoration project. While these responses explain a piece of the puzzle, monitoring of objectives at an ecosystem scale better explains the entire watershed health (Mooney et al. 2005a). Additionally, monitoring should be conducted over a longer period (10+ years) to fully understand the consequences and enhancements of restoration. The current monitoring programs

performed within the LA River are disjointed and do not test for the same objectives or criteria (City of Los Angeles and City of Burbank 2007). For successful monitoring outcomes, the different agencies need to coordinate universal objectives, methods, and reporting to determine restoration success.

Restoration is not as valuable if monitoring is not used to evaluate success. Several studies have found that very few restoration projects are monitored post-project, and of those monitored sites, even fewer utilize the monitoring data to adapt or evaluate the project (O'Donnell and Galat 2008). Adaptive management takes the next step by using post-project monitoring to alter the project if objectives are not being met. River restoration projects are plagued by uncertainty due to the variability of river functions and processes. However, adaptive management evaluates natural systems that are characterized by uncertainty (Downs and Kondolf 2002). Adaptive monitoring incorporates uncertainty, flexibility, and systematic review to provide on-going feedback for decision making. Monitoring of specific, measurable ecosystem performance and functions are used to adapt or change the restoration mechanisms in place if they are unsuccessful (Downs and Kondolf 2002). Compared to the trial and error approach, which is more costly and untimely, adaptive management is the preferred method for project evaluation (O'Donnell and Galat 2008). For adaptive management monitoring, ten years, or longer, is the ideal length of time for monitoring. However, criteria objectives must be met for three consecutive years in order to determine if restoration is successful. Utilizing adaptive management evaluates the success of a project and will ensure that restoration project objectives are met.

6.3 Next Step: Determining Economic Feasibility

Restoration treatments can be initially costly, but are profitable long-term. Cost can be driven down by an increasing demand for treatment implementation. At a watershed scale, Los Angeles' policy for new development will enforce implementation of LID on new construction (LACDPW 2013a). This policy will increase the implementation of treatments as well as decrease costs. Additionally, assigning monetary value to ecosystem services will incentivize and allow decision makers to better comprehend the long-term monetary benefits directly associated to restoring ecosystem services (Holl and Howarth 2000).

It will be more costly to maintain the current floodplain infrastructure than to implement sustainable restoration projects, which would fulfill the same role. The infrastructure in place supports flood protection of a 50-year flood. To maintain the same level of protection improvements would need to be made to increase levee height, add more bypass culverts and dredge sediment accumulation (The River Project 2013). This course of action is expensive and will only add to the problems associated with channelization. Applying a multi-project approach using on- and off-site treatments would plan for a (more substantial) 200-year flood event, providing more flood security (The River Project 2013). In addition stormwater management practices would be integrated into restoration to ensure the success of flood control treatments (Bernhardt and Palmer 2007). Restoration treatments provide the initial step towards flood protection. However, additional planning of alternative stormwater management will provide the river maintenance necessary for success. Implementing a multi-project approach will connect the agencies and stakeholders of the LA River. Together these stakeholders can solve the obstacles of water shortage and storage by utilizing the opportunities created by storm runoff, such as groundwater infiltration and storage.

The most cost-effective treatments in terms of restoring ecosystem services are drywell and grading for off-site treatments and habitat wetlands and invasive species removal for on-site treatments. Retention ponds and bypass channels were found to be the least cost-effective treatments of river restoration and only contributed to flood protection. Overall, my analysis found that off-site treatments cost less and are more sustainable than on-site treatments in terms of replacement and maintenance.

6.4 Next Step: Climate Change Implications

Looking forward, climate change will exacerbate already water-stressed freshwater ecosystems like Mediterranean-type climates. Climate change consequences include: increased temperatures, increased frequency of drought, and increased storm events. These consequences will affect overall water quality and quantity available for human and ecosystem use. Human development increases the demand for water resources during times of water scarcity (specifically summer months), stressing the environment further (Cooper et al. 2013). Another problem associated with climate change and sea level rise is salt water intrusion. Highly saline ocean water will extend farther up the Los Angeles River (Guivetchi 2014). This will affect the

water quality of the coastal groundwater basins and the habitat in the lower reaches of the river. Restoration treatments can restore ecosystem services to provide resilience to the riverine ecosystem to combat the effects of climate change.

Climate change in addition to a variable climate and urbanization make sustainable, multi-treatment approaches to river management necessary (Grantham, Merelender and Resh 2010). Management should recognize that increasing groundwater resources provides resilience for the long-term demands of development (Grantham, Merelender and Resh 2010). Climate change variables require that restoration efforts take integrated, multi-dimensional approaches to ensure long-term system resilience and water security.

6.5 Next Step: Alternatives on the Los Angeles River

The USACE determined the feasibility of restoring specific reaches along the Los Angeles River. There are four resulting alternative recommendations. Alternatives 13 and 20 have been the most significant and most controversial in restoration decision making. Alternative 13 is supported by the USACE and developers because it solves the symptoms of flooding, while keeping the same amount of area surrounding the river available for development. However, it does not take into account the opportunities of off-site restoration or restoring the health of the watershed. In contrast, alternative 20 is a more comprehensive approach that incorporates alternative stormwater management treatments. This alternative includes creation of wetland habitat at LA State Historic Park and restoration on reaches at Verdugo Wash, which has high predicted restoration success due to its connectivity through an earthen stream bed. Alternative 20 is supported by the LA City Council, LA River Revitalization Corporation, and non-profit organizations such as FoLAR, TreePeople, and Council for Watershed Health. The USACE feasibility report indicates restoration progress but failed to acknowledge key elements of climate change, flooding, and water quality restoration (Winter 2014). Alternative 20 is a good place for restoration on the LA River to begin, but more multi-purpose off-site treatments need to be integrated to plan for a more sustainable and resilient urban river system.

7.0 Summary of Findings

This study assessed restoration treatments used on urban river restoration projects in Mediterranean-type climates in Californian to understand restoration opportunities suitable for

the LA River. The LA River has been heavily altered by urbanization and will never return to its natural (pre-urbanized) state. However, within the current physical constraints there are several options available to restore and connect the natural characteristics and processes of a riverine system. Rohde et al. (2006) concluded that the main priority for restoration should be connecting the natural functions and restoring each biogeographic region of a riverine system. The functionality of a river is restored with higher success when on- and off-site treatments are combined and connected. Preserving the headwaters may be the most successful approach to restoring water quality (Bernhardt and Palmer 2007). However, in-stream water quality restoration actions are not the only options that can improve water quality throughout the urbanized regions of the watershed. The implementation of connected off-site treatments in the urbanized upper watershed will assist in restoring a more natural flow-regime, improving water quality, and reducing the impacts of urbanization.

Four large areas along the river have a high potential for on-site restoration success because they have earthen bottoms which allow for connectivity to the groundwater. In these regions, crucial provisioning and regulating ecosystem services can be restored more easily than concrete channelized regions. These four reaches within the Los Angeles River are the Sepulveda Basin, Glendale Narrows, the confluences of the Arroyo Secco, and at the mouth, near Long Beach and San Pedro (The River Project 2013, Gumprecht 2001). Natural channel bottoms accumulate sediment (supporting vegetation growth) and nutrients, and provide access to groundwater, replenishing the aquifer. Vegetated earthen beds add roughness within the river channel which decreases flow velocities, increases infiltration, and increases water retention. In the San Fernando Valley, efforts should focus on reconnecting the river streambed to the San Fernando Valley Groundwater Basin for groundwater infiltration. The native soils are highly permeable which makes infiltration feasible and increases the hydrologic connectivity along the floodplain (The River Project 2013). Restoration at these locations will improve some of the river's natural hydrologic regime.

On-site restoration treatments combined with off-site flow-regime management or LIDs replenish water storage in the watershed. Capturing the natural stormflows through filtration systems or native soils before they reach impervious surfaces or drain pipes (Burns et al. 2011, Bernhardt and Palmer 2007) is the ideal off-site restoration approach. Combining on- and off-site

treatment in the watershed increases the degree and range of provisioning and regulating ecosystem services that are restored. Non-profit organizations such as FoLAR, TreePeople, The River Project, and The Council for Watershed Health have been instrumental in raising awareness and advocating implementation and construction of LIDs and off-site treatments in the surrounding Los Angeles communities. However, residential and private treatments will be harder to enforce without incentive policies. Incentives and actual implementation will be heavily dependent upon the cost of treatments. The cost-effective analysis of treatments, in this project, will be a practical tool for non-profit organizations to use for future projects. Furthermore, off-site treatments present educational opportunities for the surrounding community to learn about urban watershed features and restoration.

The most crucial objectives for the Los Angeles River are to restore water quality, control pollution, and protect adjacent communities from flooding. Glendale Narrows is a contaminated superfund site that requires remediation actions. Additionally, urban run-off is a source of water quality degradation in the Los Angeles River. Erosion control is not a critical objective because a majority of the river is concrete lined, leaving little area for vegetation to take hold. Bioengineering streambank erosion treatments, weir/rock vane/barb, or fascines/bundles/wattles treatments, will be required in conjunction with levee removal. Certain off-site treatments restore the natural hydrologic process (the movement water via infiltration, evaporation, precipitation, and surface flow prior to entering the river) of the watershed. These treatments include: underground catchment basins, drywell and grading, bioretention, and porous pavements. Examples of these treatments have been used in the Elmer Avenue restoration, constructed by Council for Watershed Health. Levee setback and removal should only be used in areas such as Taylor Yard and the State Park because it requires a large amount of open space to be successful. The cistern or rain barrel treatment should be implemented in conjunction with another treatment, such as bioretention, to maximize the level of ecosystem services restored. These recommendations for the LA River restoration are tailored to the specific opportunities and constraints within the LA River watershed.

Bernhardt and Palmer (2007) estimated that by 2030 approximately 60% of the world's population will reside in urban areas. Therefore, it is critical that surrounding rivers and streams are restored to sustain the needs of ecosystem services for an ever-growing population.

Urbanized environments present a multitude of restoration opportunities and need a comprehensive synthesis of treatments available to this unique system. Past concrete channelization techniques have left urban rivers devoid of their natural processes and only provide flood protection. This is no longer necessary because of new LID, on- and off-site treatments and flow-regime approaches. More research and development is needed on restoration treatments, specifically in the large-scale application of the off-site approaches. Since these approaches are relatively new, more long-term monitoring is needed to comprehensively understand the opportunities and constraints. Nonetheless, this summary of treatments and lessons can be utilized as a guide for city planners, environmental non-profit organizations, and urban communities who are seeking a synthesis of the non-traditional treatment options available. Urban river restoration uses adaptive, multi-approach treatments to fulfill enhancement of ecosystem service objectives.

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